SSIFIED

408 623

DO MENTATION CENTER

FOR

A INFORMATION

VIRGINIA

IC ASSIFIED

Best Available Copy

40 8623

MEMORANDUM
RM-2695-PR
APRIL 1961

SYSTEM AND TOTAL FORCE COST ANALYSIS

David Novick

PREPARED FOR:
UNITED STATES AIR FORCE PROJECT RAND

The RAND Corporation
SANTA MONICA • CALIFORNIA

Best
Available
Copy

SUMMARY

This memorandum describes the aims, concepts, and methods of military cost analysis as developed by the Cost Analysis Department of The RAND Corporation. Like the 1956 report on Weapon System Cost Methodology,* which it replaces, the present memorandum is concerned basically with the estimation of costs for proposed military activities so that informed choices can be made among them. It extends the earlier report by considering in more detail the underlying principles of cost analysis (Chapter I), and by describing methods for analyzing the costs of total force structures as well as individual systems (Chapter III).

In Chapter II, the earlier cost categories are refined, particularly by the provision of categories for research and development activities which now constitute an increasing share of system costs. By generalizing methods and examples, the scope of analysis is extended to support and control systems as well as weapon systems. In Chapter IV, the usefulness of cost sensitivity analysis is explained and illustrated by examples. The appendix describes detailed methods of estimating system manpower requirements.

---

* The RAND Corporation, Report R-287, February 1, 1956, now withdrawn.

PREFACE

Progress in cost analysis has continued at a rapid pace since the publication of our Weapon-System Cost Methodology* in 1956. New insights, new techniques, and new applications have developed so rapidly that when we undertook to bring this publication up to date it seemed desirable to make a completely fresh start. The result is the present memorandum: an entirely new work rather than a revision of the 1956 report.

The 1956 report broke new ground in describing a methodology for making cost estimates for complete weapon systems: not only for the weapon hardware, but also for all related elements of the system, including facilities, equipment, materiel, services, and personnel. Those who are familiar with the earlier report will recognize the substance of it, although somewhat modified, in Chapter II of the present memorandum. The most important development here has been the introduction of an additional major cost category providing for research and development activities, in recognition of the fact that these activities may now represent as much as 20 or 30 per cent of total system cost.

A few words may be in order to explain the change of title.

While the earlier report dealt with the weapon in the broader context of a weapon system, the present memorandum goes further by dealing with the system in the broader context of a total force structure comprising many systems and various non-system activities. Moreover, control and support systems as well as weapon systems are considered here. Our

---

* The RAND Corporation, Report R-287, February 1, 1956.

techniques have been generalized somewhat with the expectation that they will be increasingly applied outside the weapon system field, perhaps even in the cost analysis of non-military systems.

Finally, we use the word "analysis" rather than "methodology," to emphasize that the work of cost estimation cannot be completely reduced to routine operations. It requires a refined methodology, but it also requires professionally trained insight and judgment. Chapter I, "The Aims and Concepts of Analysis," offers general guidance by considering some of the problems underlying the choice of particular techniques.

Among other concepts, the present memorandum emphasizes the basic importance of sensitivity analysis in realizing the full usefulness of cost estimates.

The vast quantities of data generated in total force cost analysis, and the numerous variations of the same basic data required in cost sensitivity analysis, indicate the need for electronic data processing methods. EDP has been adopted at RAND, and its use is described here.

Some of the differences from the 1956 report reflect the great changes in military technology which have occurred in the last five years. Our earlier examples were drawn mainly from types of manned aircraft; here we consider also missile, electronic, and space systems. We have brought our references up to date, and have indicated new and better sources of data. It must be admitted frankly, however, that while there has been improvement since 1956, the data available from the military budgeting and accounting systems still leave much to be desired from the

point of view of cost analysis There is still too little data furnished in terms of meaningful end-product activities.*

We are fully conscious that the treatment of cost analysis which we offer here still leaves a great deal requiring further development, both in concept and in method. In particular we recognize that changes in technology affect not only the types of military equipment, but also the processes of manufacture, the training of men, and the organization of the activities concerned with introducing and operating the new equipment. To keep pace with these changes, methods of cost analysis must also change and improve.

For this reason, we hope that the present memorandum will reach a wide readership and will stimulate an exchange of ideas among persons working in the field of cost analysis. This purpose can best be served if the memorandum can be circulated freely, and this requires that it be written so as to avoid the use of proprietary and security classified information. Detailed procedures and results and the values of coefficients in estimating equations therefore have had to be excluded.

Like the 1956 report, this memorandum is not the work of a single individual. Many colleagues in industry, in the Air Force, and elsewhere in RAND have given their help. However, this work is in a special sense based on the contributions of my colleagues in the RAND Cost Analysis Department, to all of whom I acknowledge my indebtedness.

---

* See, e.g., David Novick, "The Federal Budget as an Indicator of Government Intentions and the Implications of Intentions," Business and Economic Statistics, American Statistical Association, 1959.

MEMO~~RANDUM~~
RM-2695-PR
APRIL 1961

SYSTEM AND TOTAL FORCE COST ANALYSIS

David Novick.

This research is sponsored by the United States Air Force under Project RAND — Contract No. AF 49(638)-700 — monitored by the Directorate of Development Planning, Deputy Chief of Staff, Research and Technology, Hq USAF. Views or conclusions contained in this Memorandum should not be interpreted as representing the official opinion or policy of the United States Air Force. Permission to quote from or reproduce portions of this Memorandum must be obtained from The RAND Corporation.

The RAND Corporation
1700 MAIN ST. • SANTA MONICA • CALIFORNIA

CONTENTS

CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER I

AIMS AND CONCEPTS OF ANALYSIS

In choosing among alternative military systems or force structures, why do we make cost estimates? The short answer is that cost is an element of choice which we cannot ignore. To choose wisely, we must know the cost of the proposal and be able to compare it with the costs of other proposals. We must also know the benefits of the choice, and be able to compare them with the benefits of the alternative possibilities. The intelligent weighing of costs and benefits is at least as important in military management and decision making as in any other sector of government activity or in private business enterprise.

Good cost estimates for weapon and support systems are becoming increasingly important, not only because the new system proposals are often extremely costly, requiring a substantial share of the nation's resources, but also because there are so many systems competing with each other for consideration. More and more it is recognized that a proposed system cannot be judged unless both its costs and its capabilities are estimated and compared with those of alternative proposals. Both costs and capabilities are difficult to assess, particularly when we try to look several years ahead, but the assessment must be made in advance if it is to provide a basis for choice, now, among competing proposals.

It is the purpose of this memorandum to describe methods of cost analysis which are being developed under Project RAND for use in estimating weapon and support system and total force costs.

A weapon system is defined by Air Force Regulation 80-1 as follows:

> "Weapon System. Composed of equipment, skills, and techniques the composite of which forms an instrument of combat, usually,

> but not necessarily, having an aerospace vehicle as its major operational element. The complete weapon system includes all related facilities, equipment, materiel, services, and personnel required for the operation of the system, so that the instrument of combat can be considered as a self-sufficient unit of striking power in its intended operational environment."*

Support system and control system are similarly defined and are becoming increasingly important in terms of cost. While this is recognized by the present memorandum, it does not deal with them in as much detail as we should like. Much of our work in developing methods of cost analysis for these systems is still tentative and does not permit definitive presentation.

In comparing the costs of military systems, we prefer to speak of "cost analysis" rather than "cost estimation," because the identification of the appropriate elements of cost--the analytical breakdown of many complex interrelated activities and equipments--is so important a part of the method. Weapon system cost analysis is much more than an estimate of the cost of the weapon itself. Weapon procurement costs may be relatively small compared to other necessary costs, such as base facilities, training of personnel, and operating expenses; and these other costs may vary greatly from system to system. Moreover, in comparing and programming future systems as far as 5 or 10 years ahead, the costs of research and development must be taken into account. Recent experience indicates that research and development costs are rising relative to the other costs, and may be expected to rise further as technological change accelerates. In comparing alternatives, therefore, it is necessary to estimate the cost of the complete system, including directly related support costs,

---

*Air Force Regulation No. 80-1, "Research and Development, Definitions of Terms" (28 August 1959).

extending over the whole time period from the beginning of its development to its activation and on through its subsequent operation while still in the active inventory.

Cost analysis may be regarded as embracing two levels of activity:

(1) The development of the principles and techniques of analysis, including cost estimating relationships, such as cost-quantity equations.

(2) The use of these in deriving cost estimates for specific systems.

The present memorandum does not attempt to give a complete description of cost analysis in either sense. The development of techniques is going forward actively and there is a great deal of work remaining to be done. A new problem for analysis often requires the development of new methods. Success in weapon systems cost analysis depends on the ability to carry out the research necessary to establish new data relationships and to develop new analytical tools tailored to each new set of cases. It would be misleading to suggest otherwise by describing specific procedures in too much detail. Moreover, if we included sample cost analyses of real (or plausibly simulated) systems, we should have to impose narrow limits on the distribution of this memorandum, so as to protect proprietary data and military security. Nonetheless we hope that the description of principles and techniques, and the examples of worksheets and other materials, will enable cost analysts and others to understand our methods and adapt them to their own specific problems.

The making of complex management decisions has been assisted in recent years by the development of "systems analysis," the methodical examination of alternatives in terms of quantitative estimates of costs

and benefits.* It is necessary, we believe, to think of weapon cost analysis, not as an end in itself, but as a part of a total systems analysis which has, as its other limb, the quantitative study of the military effectiveness of proposed systems. In our work, we have made it our purpose to treat cost as an integral part of weapon system analysis. This aim is reflected in the nature of the costing concepts, the analytical techniques, and the methods of presenting results which are described in the following pages. It is hoped that the reader is already familiar with the general principles of systems analysis. With such knowledge, he will find it easier to understand the purpose of the present memorandum, and to apply its techniques to his own needs.

By way of introduction, let us consider two common ways in which cost and effectiveness may enter into analysis.

Following one traditional approach, we may assume that we have only a given amount of resources--a fixed budget--and that our problem is to select the most effective system which we can buy for the money. The first step is to determine, through cost analysis, the number of units which we could buy of each of the alternative systems. Having determined the units of force purchasable in each case, our next step is to make an effectiveness analysis. The effectiveness of each of the alternative forces is

*See, e.g., C. J. Hitch, An Appreciation of Systems Analysis, The RAND Corporation, Paper P-699, August 18, 1955; M. W. Hoag, An Introduction to Systems Analysis, The RAND Corporation, Research Memorandum RM-1678 (ASTIA No. AD 101071), April 18, 1956; Herman Kahn and Irwin Mann, Techniques of Systems Analysis, The RAND Corporation, Research Memorandum RM-1829-1 (ASTIA No. AD 133012), June 1957; A. J. Wohlstetter, Systems Analysis Versus Systems Design, The RAND Corporation, Paper P-1530, October 29, 1958; and C. J. Hitch and R. N. McKean, The Economics of Defense in the Nuclear Age, The RAND Corporation; Report R-346, March 1960, also published by Harvard University Press, Cambridge, Massachusetts, 1960.

estimated in terms of some agreed criterion, for example, the number of targets which each force could destroy.

This estimate is usually achieved by means of campaign or battle models. These models are sometimes complex mathematical constructions designed for use with electronic computers, but the basic idea is illustrated in Fig. 1, a simplified diagram of a model for strategic missile strikes. Starting at the top, the units of force are inserted in the model, and, after appropriate manipulations, the total effectiveness of the force comes out in terms of hits on targets at the bottom of the diagram.

Applying the criterion of maximum targets hit for a given budget, one could then select the "best" of the alternative weapon systems or combination of systems.

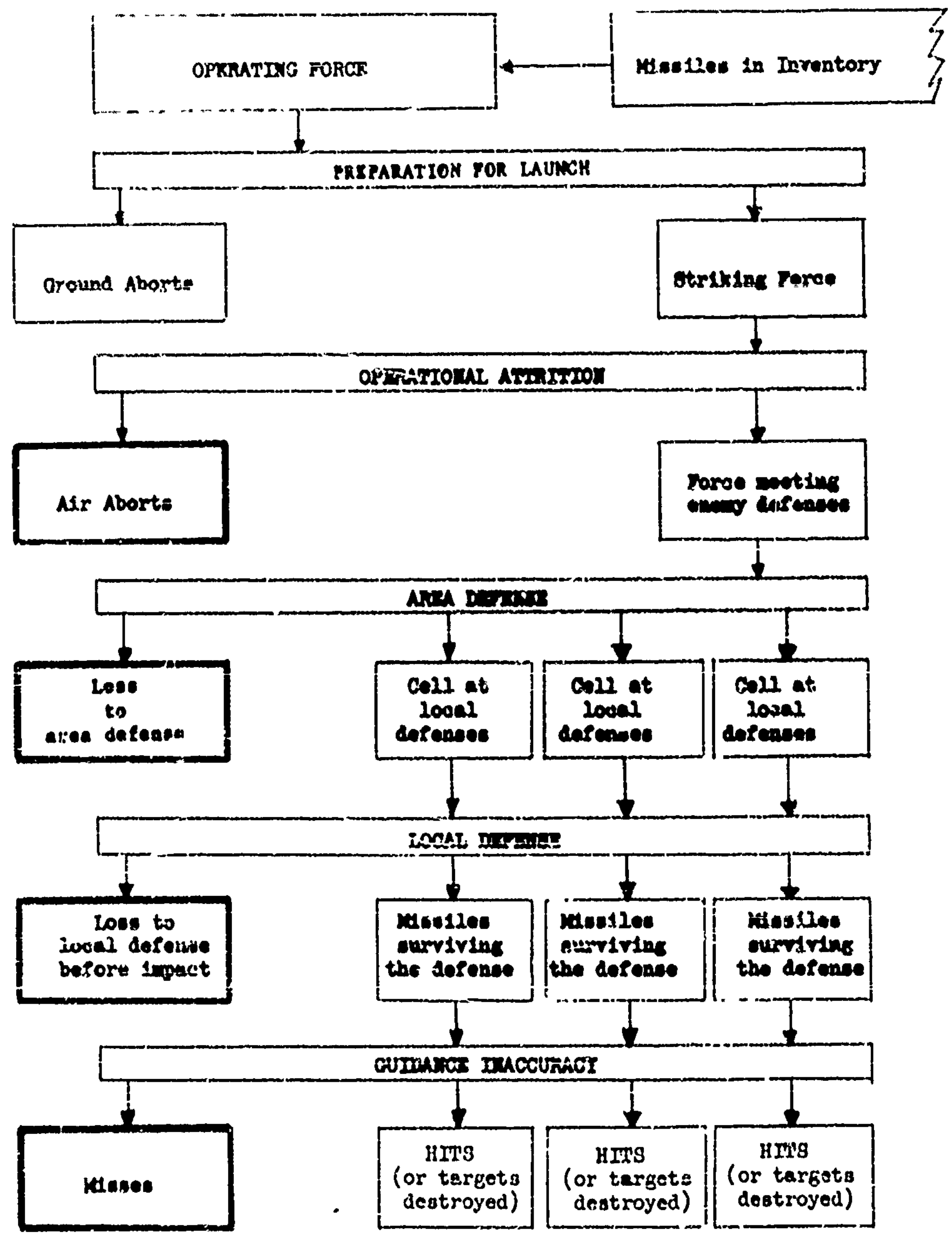
Another approach is often followed, beginning with a certain desired military capability--a fixed effectiveness.

Here the effectiveness model is also used, but one starts at the bottom, with a given number of targets to be destroyed. One works upwards, estimating in each case the number of units of force of a particular weapon system which must be bought at the beginning to achieve the desired end result. These forces are then costed and, applying the criterion of least cost for a given effectiveness, one could then select the "best" of the alternative weapon systems.

This is, of course, a much simplified description. In every real analysis, however, cost and effectiveness are the key factors in decision. For this reason, this type of analysis is sometimes referred to as "cost-effectiveness" analysis.

Fig. 1

EFFECTIVENESS ANALYSIS: DIAGRAM FOR STRATEGIC MISSILE STRIKES



In the two examples given above, cost is held fixed in one case, effectiveness in the other. But in each case, cost analysis must be carried out in detail. Where total expenditure is "given," cost analysis is still necessary, for it is only by costing the units of force that we can find out how much of each force is attainable from a given budget.

Weapon systems cost analysis has proved its usefulness in military management even where a formal quantitative analysis of system effectiveness has not been undertaken. There is reason to believe that in the future there will be increasing emphasis on the costing of proposed systems as a preliminary step in decision making.

What do we mean by cost? In speaking of a fixed budget, we have implied a dollar cost. For most purposes dollar costs are a sufficiently meaningful measure of the resources needed to develop, procure, and operate a weapon system. Moreover, in fixing our attention on the weapon system as a whole, we need some way of representing a sum of many dissimilar resources--manpower, missiles, base installations, training schools, etc. These items can best be aggregated in terms of the dollars which will buy them. Thus systems analysts and military planners generally find it convenient to represent total resources by dollar cost. In generating the dollar cost--in weapon systems cost analysis--the major components of the system are, of course, described in terms of categories of physical resources. This description of physical resources is often extremely useful in itself, in calling attention to major differences between systems, and in identifying unrealistic choices, e.g., systems which would exceed the possible supplies of a given resource--say, technical manpower.

In using dollar cost, questions naturally arise about possible

changes in the price level in future years. However, if we reflect on the purpose of the analysis, it appears that changes in price level will usually not significantly affect the result. What is wanted is a method for broad comparison of costs of competing systems in a given year or over a period of years. As inflation or deflation will presumably affect the costs of the various systems in essentially the same way, it is convenient to assume a stable price level or a "constant dollar." In any case, if there is special interest in the effects of price-level changes, it is usually easiest to begin with cost estimates in terms of constant dollars and then to modify these in accordance with the expected course of future prices.

Moreover even in the best system analysis other future uncertainties are very large. Systems will be subject to many unforeseen changes in configuration as they advance through future years from research and development through procurement to operational use. The effects of these changes have cost implications which are almost sure to be greater than the effects of any probable change in the general level of prices. The methods of cost analysis described here seek meaningful comparisons among systems, recognizing that in long-range projections only the dominant differences can be used to distinguish one proposed system from another. We do not aim at an accuracy of detail such as would be required for estimates for the procurement of specific items or the recruitment and training of personnel to be used in, say, next year's military budget.

Although possible changes in the future price level may be relatively unimportant in systems analysis, the incidence of cost from year to year may be an important consideration in programming systems into future force

structures, particularly when tight ceilings are expected on the over-all budget. The annual incidence of costs--the time phasing of costs--is therefore an important concept in our cost analysis system. It is not always sufficient to describe the cost of a system by means of a single figure representing total expenditure at the end of a long period of years. Successive annual totals (sometimes referred to as cost streams) may be computed for each system under consideration. Comparing the future cost streams of competing systems is somewhat more difficult but often more useful than comparing simple "lump sum" costs.

Closely related to the time-phasing of system costs is the concept of incremental costing. A new generation of weapons can often use, or use in part, the facilities created for earlier generations When B-52s came into use, many existing base facilities could be used by the B-52 wings. In calculating the cost of base facilities for the B-52 system it was therefore necessary to include only the additional (and in this case relatively small) expenditures necessary to adapt the facilities for the new use. Incremental costing can significantly affect choices where one of the competing systems can take advantage of existing military assets.

Until recently, the choice among weapons was a somewhat isolated procurement decision. But in the last decade the choices--and the problems of military planning--have become much more interconnected. Among the reasons for this may be mentioned the increasing rapidity of technological change, the greater complexity of the new systems, the length of time required for their development and production, and their greater dependence upon other weapon and supporting systems within the same service and in the other services as well.

These interdependencies are recognized in the RAND concept of total activity cost. Under this concept, a proposed system is examined in terms of units of combat capability placed in a complete operational context. In the Air Force, these units are typically wings, squadrons, or sites. For a B-52 wing, for example, costs include not only the "hardware," personnel, and basing costs easily identified at the wing level, but also the costs of necessary supporting activities, such as Air Training Command replacement training and Air Materiel Command depot maintenance associated directly with the B-52 system.

From what has already been said about the significance of time-phasing in systems cost analysis, it will be apparent that there are advantages in clearly identifying costs as they occur in natural time sequence. Before a new system can be procured, it must be developed, and this involves a series of research and development costs. When the new system is adopted and is being introduced into the active inventory, there are expenditures for procurement, basing, initial training, etc. Finally, there are annual operation expenses. These natural time divisions are identified as separate categories in the RAND costing structure.

Estimates of the total cost of a system are developed by a process of analysis and synthesis. Major categories and subcategories of resources are identified and grouped, and their dollar costs estimated and summed. Subtotals are developed which represent the estimated system costs for (1) research and development, (2) investment, and (3) operation.

These three major categories are analyzed in detail in the next chapter. At this point it need only be said that system cost analysis is not a mechanical operation. It requires judgment, skill and objectivity on the part of the analyst. The analyst must take particular care

with these elements of cost which are specially sensitive to differences in system characteristics or methods of operation, for these are often the key to differences in total cost between competing systems. It should be emphasized, too, that the primary purpose of cost analysis is comparison: to provide estimates of the comparative or relative costs of competing systems, not to forecast precisely accurate costs suitable for budget administration. Comparison is aided by consistency in method: by ensuring the similar treatment of similar items of cost in different systems. Consistency also requires that each system be given the benefits derivable from existing assets.

We have spoken so far as if system cost analysis were limited to comparisons of individual systems. In the past this was often true, although what has already been said above about incremental costing and time-phasing of costs should suggest that alternative systems cannot be fully compared without taking into account the other systems and non-system elements which constitute the existing (or projected) "total force structure."

If the total force is costed both with and without the addition of a particular system, the difference between the two total costs is the cost of the system. Here the comparison of costs between two competing systems is a comparison of the additional or "marginal" costs incurred in each case in adding the new system to the total force. This type of study requires, therefore, a more complete and profound analysis of costs than is necessary for system comparisons carried out, as it were, in isolation.

There are good reasons for regarding cost analysis of the total force structure as one of the main goals toward which research in military

cost analysis should be directed. We rely on and pay for the effectiveness of the total force. The military services are attempting to achieve the most effective over-all "mix" of weapon and other systems for a given cost, or the least cost for a given total effectiveness--in short, the most efficient use of all the resources which the nation allocates to defense.

From this point of view, individual weapon systems cost analysis is an example of what is called lower level "sub-optimization" in systems analysis. It is the seeking of efficiency in the small, while total force structure analysis aims at efficiency in the large.*

It must be admitted that there are difficulties involved in carrying out the effectiveness analysis of alternative total force structures. But even if the total effectiveness of the various possible combinations of systems should be largely a matter for subjective judgment, it is still imperative to know what the costs are likely to be.

---

*See Hitch and McKean, op. cit., pp. 125-133 for a discussion of sub-optimizing.

CHAPTER II

COST ANALYSIS OF INDIVIDUAL SYSTEMS

This chapter is concerned with cost estimation for individual systems, and it simplifies the problem by looking at each system as if it were more or less isolated from other systems within the total force structure. It fixes attention on the various elements within and directly related to the system and describes methods for their ordered, step-by-step analysis. As we have already indicated, this is but one approach to the cost analysis of an individual system; the system cost may also be derived, through total force cost analysis, as the marginal cost involved in adding the system to the force structure. While the advantages of the latter approach are more and more recognized, it is not always possible to carry out a total force analysis; and if a quick, gross comparison of several rather similar systems is required, the total force method may be unnecessarily refined for the purpose. Moreover, many of the basic methods of costing are the same whether we look at isolated systems or aggregations of systems. The present chapter therefore provides a foundation for total force cost analysis.

The first thing an analyst must do is to make sure that he understands the system he is working with. He should begin his work by gathering sufficient descriptive material and data. The degree of detail of this information depends upon the nature of the system; and part of the skill of the analyst lies in selecting and seeking out the specifications he needs. The list in Table 1 is typical, and gives an idea of the complexity of the analyst's task. Of course, many of the specifications will be uncertain approximations, especially for systems whose operational use lies far in

Table 1

SYSTEM SPECIFICATIONS AND ASSUMPTIONS (EXAMPLES)

I. Primary equipment specifications (if possible by major components, e.g., airframe or structure, propulsion, guidance).

A. Performance specifications

1. Examples for airframes
   a. Speed
   b. Combat radius
   c. Climb
   d. Ceiling
   e. Range
   f. Load

2. Examples for electronics
   a. Frequency
   b. Continuous vs. spasmodic operation
   c. Functions to be performed and speed of computation
   d. Accuracy (e.g., in terms of deviation over time and/or drift rate, discrimination capability, etc.)
   e. Jamability

3. Examples for engines
   a. Rating
   b. Specific fuel consumption
   c. Operating temperature

B. Weight data

C. Other physical data

1. Examples for airframes
   a. Size data (e.g., fuselage length, wing area, wing span, etc.)
   b. Construction characteristics
      (1) Sheet and stringer
      (2) Sandwich, waffle, etc.
      (3) Foamed metal
      (4) Welded vs. riveted
      (5) Castings, forgings, extrusions, weldments, etc.
   c. Basic metal types (with respect to items in b. above)
   d. Tolerances (with respect to items in b. above)

2. Examples for electronics
   a. Volume
   b. Type of construction technique (tube, transistor, modular)
   c. Number of tubes or transistors
   d. Number of stages
   e. Power requirement
   f. Antenna diameter (for radars)

D. Who the manufacturer is or is likely to be.

II. Ground support equipment specifications analogous to those listed under I.

III. Operational concept specifications or assumptions and related matters. Examples are:

A. Force size
B. Geographical deployment (especially overseas vs. ZI)
C. Dispersal scheme
D. Activity rates
E. Fixed or mobile system and description thereof
F. "Hard" or "soft" system, and psi specification if hard
G. Organizational concept: wing, group, etc., and number of squadrons per wing or group
H. Alert capability and related manning concept
I. Degree of system automation, stated by function if possible, in relation to manning and OSE requirements
J. Number of years the system is to be in the operational inventory
K. Training concepts; and in the case of missile systems: (a) number of missiles to be used in initial training, (b) number of live firings for "proficiency" training purposes per year
L. Logistics support concepts, especially regarding depot maintenance (AMC depot, or contractor?). Is there to be a "central support" area?
M. Permanent or temporary facilities?
N. Tenant or nontenant operation?
O. Main aspects of the development program, especially number of vehicles in the test inventory.

the future, and for those a range of likely values should be obtained rather than a single value.

In addition to the information in such lists, the analyst needs a basic frame of reference, generally applicable to all systems, and specifically designed for cost analysis. In our experience, the following characteristics are desirable in a set of cost analysis categories:

(1) Provision should be made for segregating total cost into the three major time-phases:

  (a) Research and Development
  (b) Investment (procurement and placing in operational use), and
  (c) Operation (cost of operation over a period of years).

(2) The set should be as all-inclusive as possible so as to preclude the omission of significant elements of cost.

(3) The cost categories should be designed in a way that will facilitate determination of those elements of the system which have the greatest impact on total cost, and which are most sensitive to changes in hardware characteristics or variations in operational concept.

As a result of experience with a variety of analytical schemes, we have developed the framework of cost analysis categories given below in Table 2.

Those who are familiar with our earlier report on weapon-system cost methodology will recognize many of these elements.* The principal change introduced as a result of more recent experience is the separate category for research and development costs. The research and development category was added because of the increasing magnitude of these costs relative to the total military budget, and because of the greater usefulness of an analysis which programs costs over the whole life-cycle of the system,

---

*R-287, now replaced by the present Research Memorandum.

Table 2

COST ANALYSIS CATEGORIES FOR INDIVIDUAL SYSTEMS

I. Research and development costs

   A. System development
   B. System test and evaluation
   C. Other system costs

II. Investment costs

   A. Installations
   B. Equipment

      1. Primary mission
      2. Specialized
      3. Other

   C. Stocks

      1. Initial stock levels
      2. Equipment spares and spare parts (initial)

   D. Initial training
   E. Miscellaneous

      1. Initial transportation
      2. Initial travel
      3. Intermediate and support major command

III. Operation costs

   A. Equipment and installations replacement

      1. Primary mission equipment
      2. Specialized equipment
      3. Other equipment
      4. Installations

   B. Maintenance

      1. Primary mission equipment
      2. Specialized equipment
      3. Other equipment
      4. Installations

   C. Pay and Allowances
   D. Training
   E. Fuels, lubricants and propellants

      1. Primary mission equipment
      2. Other

   F. Services and miscellaneous

      1. Transportation
      2. Travel
      3. Other (including maintenance of organizational equipment)

   G. Intermediate and support major command operating cost (only exceptionally included in cost analysis of individual systems)

beginning with initial development.

Figures 2a and 2b show in simplified form the cost history of a typical weapon system. In Fig. 2a the costs for each of the three basic categories are represented by smoothed curves, overlapping somewhat, but typically displaying successive maxima. Figure 2b portrays the same data for successive fiscal years by means of a bar graph on a slightly different scale. Here the height of the bar shows the total expenditure during the year for all three categories.

In the discussion that follows, it is helpful to keep these figures in mind. Chronologically, we should begin with a description of research and development costs, proceed to investment and end with operation costs. However, because of the very nature of research and development activities with their long lead times and elements of uncertainty, the costing of this category presents special difficulties. It is less routine and more speculative and draws heavily on professional insight and judgment. It would be an advantage to the reader, if he is not already experienced in cost analysis, to approach the problems of research and development costing after he has been introduced to investment and operation costing. This is the plan of exposition we have adopted here.

Investment Costs

Investment costs are those one-time outlays required to introduce a new capability into the operational force, after the required equipment has been developed and tested to an acceptable level of reliability. This new capability may be represented by a new weapon system or a modification of an existing one--for example, a new air-to-surface missile introduced into an existing strategic bombing system. Investment costs are also

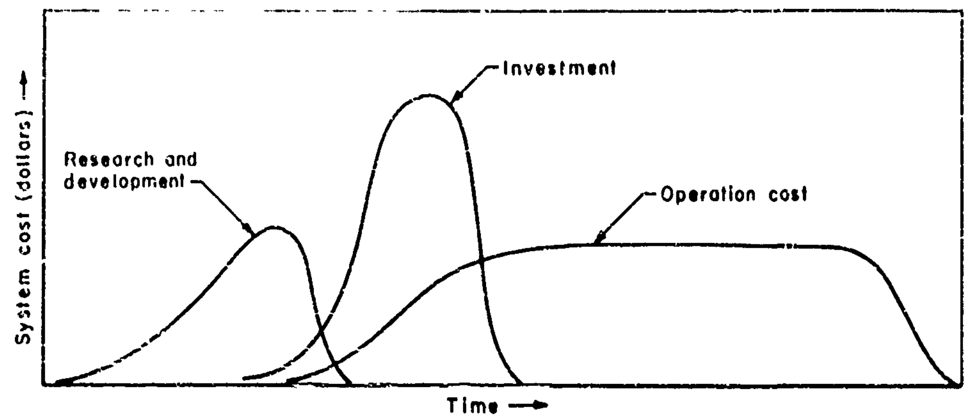


Fig. 2a — System costs time phasing (idealized curves)

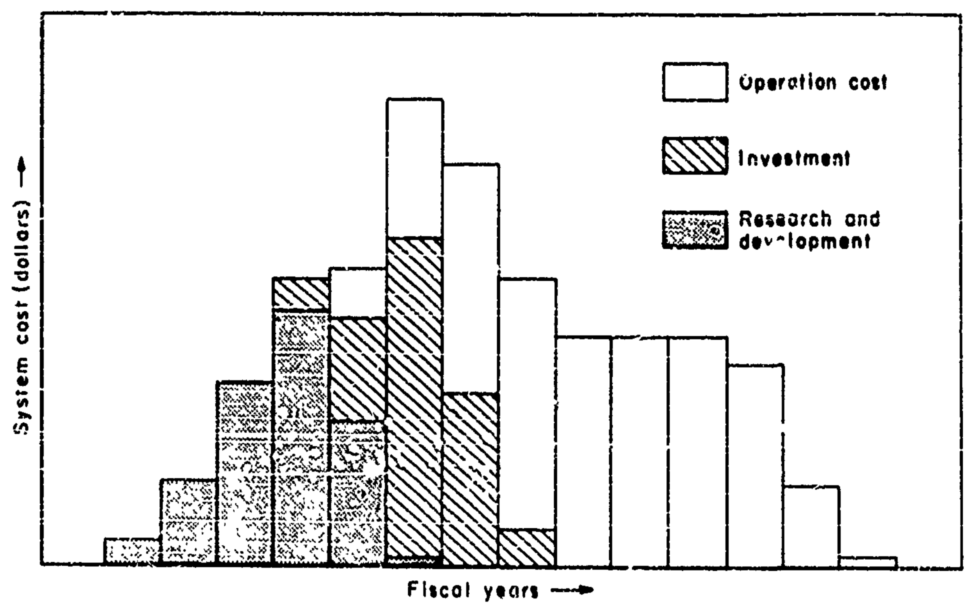


Fig. 2b — System costs time-phasing (by fiscal years)

generated in the non-systems part of the Air Force. Initial outlays for additional personnel facilities at Headquarters SAC and for a new warehouse at an AMC depot are illustrations of such investment costs. In what follows, we shall describe each of the investment costs listed in Table 2.

INSTALLATIONS

Introduction of a new weapon system into the Air Force inventory usually implies a substantial investment in installations. This is particularly true if additional bases have to be constructed, but even if a new weapon is phased-in on an existing base structure, some investment in facilities is usually necessary. Runways may have to be lengthened, launch pads constructed, new maintenance shops provided, additional personnel facilities built. Whether new installations are constructed or existing ones modified, the costs are included under the heading of installations.

Installations cost structures

A good starting point for detailing the elements of this category is the Air Force nomenclature for real property,* with which the military cost analyst should make himself thoroughly familiar. The main headings are listed in Table 3.

For systems being phased into the active force in the near future, this nomenclature should be adequate as a basis for installations cost analysis. For systems of the more distant future--especially satellite and advanced missile systems--modifications are usually required. For

*Air Force Manual No. 93-2, Real Property Standard Codes and Nomenclature.

Table 3

BASIC PROPERTY NOMENCLATURE

- Operational facilities
  - Airfield pavements
  - Fuel dispensing facilities
  - Communications and navigational facilities
  - Land operational facilities
- Training facilities
  - Training buildings
  - Training ranges and drill fields
- Maintenance facilities
  - Aircraft
  - Guided missiles
  - Automotive
  - Weapons
  - Ammunition
  - Electronics and Communications
  - Other
- Supply facilities
  - Liquid fuel storage
  - Ammunition storage
  - Cold storage
  - Covered storage
  - Open storage
- Hospital and medical facilities
  - Hospital buildings
  - Laboratories and clinics
  - Dental clinics
  - Dispensaries
- Administrative facilities
  - Administrative buildings
  - Administrative structures, underground
  - Other
- Housing and community facilities
  - Family housing
  - Troop housing
  - Community facilities
    - Personnel support and services
    - Morale, welfare and recreation (interior)
    - Morale, welfare and recreation (exterior)
- Utilities and ground improvements
  - Electrical facilities
  - Heating facilities
  - Sewage and refuse facilities
  - Water facilities
  - Roads and sidewalks
  - Railroads
  - Ground drainage and fencing
  - Fire and other alarm systems
  - Miscellaneous facilities
- Land

example, several new missile system proposals involve squadron-dispersed launch sites with a central support area for a group of three or four squadrons. In cases like this, we have found the following check list to be useful:

Installations at the dispersed squadron launch sites
- Launch pads (or pits if sites are hardened)
- Propellant storage, transfer and decontamination facilities
- Blockhouse and tunneling
- Utilities

Installations at the central support area
- Training facilities
- Maintenance facilities
- Supply facilities
- Medical facilities
- Administrative facilities
- Housing and community facilities
- Utilities

Remote tracking, monitoring, and communications facilities

Estimating Methods

Methods of estimating installations investment cost may vary considerably depending upon the nature of the problem at hand. Generation of definitive and detailed estimates for a well-defined system requires analysis of the installations cost structure item by item, specifying the physical requirements in terms of the relevant unit of measure and multiplying these requirements by the appropriate construction cost factors.

The determination of physical requirements deserves special emphasis, especially if a new system is being phased in on an existing base structure. This is essential in determining incremental requirements. Assume for example that system A is to be phased in on existing bases X, Y and Z, and that the total runway requirement for system A is 8,000 feet. The incremental requirement for runways for system A would be determined as follows:

Base	System A runway requirement (feet)	Existing runway available at each base (feet)	Incremental requirement for system A
X	8,000	6,000	2,000
Y	8,000	9,000	0
Z	8,000	7,000	1,000
	Total system requirement		3,000

This is of course a much simplified example. In addition to lengthening, there may be incremental requirements for widening and strengthening. Requirements for these and other installations categories would be determined in a similar way.

The important point is that a detailed base-by-base analysis is required if incremental requirements are to be determined with maximum precision. But in many instances this approach is not practicable or even possible. If the system under consideration has a proposed operational date five to ten years from now, a detailed base-by-base analysis is not possible, because the USAF base deployment and utilization program does not extend that far into the future. An alternative is to examine in detail a small sample of bases which might be used by the new system, determine a typical or average set of installations requirements from the sample, price out these requirements, and use the result as the installations cost for a typical base to be used by the system. The total for the system would then be obtained by multiplying this "average" cost by the total number of bases required. In some cases this method may result in a rather crude estimate, but it is preferable to having no sample at all, and it is certainly better than assuming that all installations will be constructed

new if in fact the system under study is likely to take considerable advantage of base facilities already on hand.

There are two principal kinds of information about installations needed in cost analysis: physical requirements, and construction cost factors. In the determination of physical requirements, the USAF Standard Installations Facility Requirements Manual (AFM 86-4) is basic, particularly for current and near-future systems. For systems of the more distant future, this manual must usually be supplemented by examination of the specifications of the system and its operational concepts. Very often these specifications are not sufficiently definite, and the analyst must consult with the system designers and attempt to work out an operational concept from which installations requirements can be inferred.

Physical requirements are converted into estimates of installations cost through the use of construction cost factors--dollars per square yard of runway, hospital cost per bed, vehicle maintenance shop cost per square foot, etc. Construction cost factors for a wide variety of installations categories and geographical locations may be obtained from Air Force and other publications.*

In contrast to cost analysis problems where detailed and fairly definitive estimates are necessary, there are many instances where less

*For example, see Pricing Guide for Permanent Construction in Continental U.S.A., Directorate of Installations, HqUSAF, October 1958; Department of the Army, Empirical Cost Estimates for Permanent Military Construction, 17 February 1956; "1957 Construction Costs and Price Trends: Factors for Estimating Costs Outside the U.S.," Engineering News-Record, October 17, 1957, p. 288.

precise estimates will suffice. In the early stages of a comprehensive systems analysis study there may be a very large number of alternatives to be considered. The problem is to screen these alternatives with a view to weeding out the obviously unattractive ones. Numerous quick analyses may be required to do this; and for these only crude estimates are usually needed. Here a generalized cost-estimating equation may be very useful. These equations are functional relations between major categories of installations cost and key weapon system characteristics. They are derived by detailed study of changes in installation costs as hardware characteristics and operational concepts are varied over relevant ranges for the principle classes of weapon systems. For underground ballistic missile systems, for example, RAND has developed generalized cost-estimating equations to express the major categories of installation costs as functions of:

Missile characteristics (length, diameter, and weight)
Various levels of psi overpressure
Number of missile pits
Number of spare missiles
Number of personnel
Length of tunnel to guidance buildings
Site clearance
Miles of road from base to main highway
Distance from public utility lines to base
Number of guidance buildings
Number of guidance building tunnels
Tons of LOX required per missile (including losses)
Tons of fuel required per missile

Similar types of generalized equations have also been developed for various classes of manned aircraft systems.

EQUIPMENT

Expenditures for equipment are often the largest of all the investment outlays in dollars required to establish a new Air Force combat

capability. An extremely wide variety of equipment is needed--varying from missiles, mission aircraft, and prime radars and the associated ground support equipment, to stoves and tables used in mess halls.

Our procedure summarizes the initial equipment costs for a combat squadron under four main categories: (1) primary mission equipment, (2) specialized equipment, and (3) other equipment. Investment in equipment for the direct support of the system at the support major command level is included in the miscellaneous category II E.

Primary Mission Equipment

This category represents the initial cost of the primary mission equipment assigned to combat organizations. It includes the total cost of the equipment itself (including all government-furnished equipment), but excludes initial spares and spare parts. These latter items, although procured along with the equipment, are accounted for under stocks (category II C).

Since the unit cost of any particular item of equipment depends to a considerable extent upon the number of items produced, the cost-estimating process for primary mission equipment must be an integrated one embracing not only the deliveries of equipment to the combat organization, but also items of equipment accounted for in other cost categories. The RAND procedure therefore provides for simultaneous estimation of the cost of the equipment assigned to various cost categories, such as research and development, primary mission equipment, support major command investment, initial training (for missiles), equipment replacement and annual training.

Consider an aircraft system as an example, missiles and other systems being treated in a similar fashion. The starting point is the aircraft delivery schedule. For each fiscal year, the total deliveries are broken

down into: (1) those scheduled for test and evaluation purposes (charged to research and development cost); (2) those scheduled for delivery to support major commands, primarily the Air Training Command for training purposes (charged as an investment cost to the intermediate and support major command investment category); (3) those required for combat squadron attrition (charged as an annual operating cost to the primary mission equipment replacement category); and (4) the net deliveries available for assignment as combat unit equipment (charged as an investment cost in the primary mission equipment category). The result is that the complete production run for the aircraft is accounted for in the costing procedure at the proper point in time, using the appropriate unit cost taken from a cost-quantity curve* for the aircraft. A simplified example of this procedure is shown in Table 4.

For equipment for which production contracts have been let (or are about to be let), unit prices are sometimes obtained from Air Force budget estimates. If the "quantity produced" figure associated with this unit price differs significantly from the quantity assumed in the weapon systems study, the unit price is adjusted on the basis of an appropriate cost-quantity relationship.

If these budget estimates are not available or are not appropriate--the usual situation in dealing with advanced systems--equipment cost must be built up by summing the costs of major components by cost element for each component.** Examples of major component structures are given in

---

*For a discussion of cost-quantity relations, see Harold Asher, Cost-Quantity Relationships in the Airframe Industry, The RAND Corporation, Report R-291, July 1, 1956.

**In a sense this technique represents an intermediate approach between highly aggregative and extremely detailed equipment cost estimating. (For examples of the latter, see L. P. Alford and John R. Bangs, Production Handbook, The Ronald Press, New York, 1953, pp. 1029-1092; and Tool Engineers Handbook, McGraw-Hill Book Company, Inc., New York, 1949, pp. 25-45.) For most problems encountered in the type of cost analysis under consideration here, the intermediate approach represents an appropriate level of detail.

Table 4

INTEGRATED COSTING OF PRIMARY EQUIPMENT FOR AN AIRCRAFT SYSTEM
(Average costs taken from appropriate aircraft
cost-quantity curves; all numbers hypothetical)

	Time Period					
	T_1	T_2	T_3	T_4	T_5	T_6
Total aircraft deliveries per time period:	2	40	250	450	460	9
Assignment to cost categories:						
Innovation						
Number of aircraft	2	30	5			
Average cost in millions (including spares)	$9	(10 at $7 (20 at $4	$2.5			
Total cost (millions)	$18	$150	$12.5			
Support major command investment (e.g., ATC)						
Number of aircraft		1	3			
Average cost in millions (including spares)		$4	$2.5			
Total cost (millions)		$4	$7.5			
Primary mission equipment replacement (attrition):						
Number of aircraft		1	7	30	45	9
Average cost in millions (including spares)		$4	$2.5	$1.9	$1.6	$1.5
Total cost (millions)		$4	$17.5	$57.0	$72.0	$13.5
Primary mission equipment investment in the combat squadrons:						
Number of aircraft		8	235	420	415	
Average cost in millions (excluding spares)		$2.5	$2.0	$1.5	$1.3	
Total cost in millions (excluding spares)		$20	$470.0	$630.0	$539.5	
Initial spares (charged to the "stocks" category)		$6	$141.0	$189.0	$161.9	

Table 5, and cost element structures in Table 6.

In using these structures in cost estimation, it is necessary to analyze historical data and develop cost-estimating relationships for the various elements in each of the major component areas (airframe, engines, electronics, etc.). A few examples of such relationships are given in Table 7.

In some instances the historical records and the relationships derived from them are of limited usefulness. Consider the problem of estimating the cost of mach 3 stainless steel bomber airframes, utilizing a substantial amount of honeycomb sandwich structure. There are at the time of writing almost no applicable historical records. The limited experience on stainless steel airframes (the Navaho and X-15) and the records for the current bombers (B-52 and B-58) provide an important point of departure, but little more. It is necessary to utilize all available information about techniques being developed for fabricating stainless steel structures. One way to proceed is to break the airframe down into its components, examine the proposed fabricating operations for each component, try to determine the major differences between these operations and the ones typically performed on conventional aluminum structures, and finally to translate these differences into new cost-estimating relationships (for labor, material, overhead, etc.), using the old relationships as a starting point.*

Thus, with respect to direct labor, we might construct a table for a given airframe component as follows:

*See R. W. Smith, Generalized Cost Functions for Mach 3 Airframes (U), The RAND Corporation, Research Memorandum RM-2336 (ASTIA No. AD 312114), March 3, 1959 (Confidential).

Table 5

EQUIPMENT COMPONENTS (EXAMPLES)

Component structure for a ballistic missile (or similar aerospace vehicle)

- Airframe
  - Structural
    - Leading edges
    - Body skin (including tankage)
    - Structural members (frame)
  - Sub-systems (electrical)
  - Controls (electromechanical)
- Power Plant
  - Liquid rocket
    - Pump drive assembly
      - Turbo-pump
      - Gas generator
    - Thrust chamber
    - Propellant lines and fittings
    - Vernier and exhaust system
    - Frame or mounting structure
    - Accessory power supply
  - Solid rocket
    - Casing
    - Nozzle
    - Propellant
- Guidance
  - Inertial
    - Inertial measurement unit
      - Platform
      - Accelerometers
      - Gyroscopes
    - Computers
    - Control central & associated electronics
  - Radio command
    - Decoder
    - Beacons
    - Antenna
- Payload
  - Nose cone
    - Shell
    - Arming and fusing
  - Warhead

Component structure for a prime radar

- Antenna and wave guide
- Transmitter
- Modulator
- Pulse compression equipment
- Receivers
- Power supply equipment
- Miscellaneous
  - Velocity filter
  - Moving target indicator group
  - Cabling
  - Other

Component structure for a bomber aircraft

- Airframe
  - Wings
  - Fuselage
  - Empennage
  - Miscellaneous
- Propulsion system
- Electronics
  - Bombing navigation & missile guidance system
  - Defense electronics system
  - Mission and traffic control system
  - Other
- Offensive missile (ASM)
  - Airframe
  - Propulsion
  - Electronics
- Defense missile (if any)
- Miscellaneous

Component structure for fighter aircraft

- Airframe
  - Wings
  - Fuselage
  - Empennage
  - Miscellaneous
- Propulsion system
- Electronics
  - Fire control system
  - Mission and traffic control system
  - Other
- GAR or other type of missile
  - Airframe
  - Propulsion
  - Electronics
- Miscellaneous

Table 6

COST ELEMENTS OF EQUIPMENT COMPONENTS

(Applicable generally to items of major equipment)

- Manufacturing
  - Direct labor
  - Material
    - Raw materials
    - Purchased parts
    - Subcontracted items
  - Manufacturing overhead
    - Fixed
    - Variable
- Tooling
  - Direct labor
  - Material
  - Overhead
- Production engineering
  - Direct labor
  - Material
  - Overhead
- Engineering changes
- Publications
- General and administrative expense
- Profit
- Industrial facilities (if required)

Table 7

COST-ESTIMATING RELATIONSHIPS (EXAMPLES)

(1) Airframe direct labor cost per pound of airframe weight as a function of cumulative output and/or rate of output

(2) Cost per pound of airframe weight adjustment to be used in conjunction with (1) above. (This is necessary because past experience indicates that production cost per pound tends to vary inversely with the weight of the airframe.)

(3) Airborne radar equipment cost as a function of:
 a. Cumulative output
 b. Rate of output
 c. Performance characteristics (e.g., frequency, accuracy, jamability, discrimination capability)
 d. Physical characteristics (e.g., volume, number of tubes or transistors, number of stages)
 e. Combinations of the above

(4) Manufacturing overhead cost (for various classes of components) broken down into "fixed" and "variable," with the variable portion expressed as a function of rate of output, cumulative output, degree of utilization of plant capacity, etc.

(5) Material cost per pound (for various types of components) as a function of cumulative output

(6) Engineering cost (for various classes of components) as a function of:
 a. Cumulative output
 b. Peak production rate
 c. Weight of the component
 d. Slope of the direct labor progress curve
 e. Performance characteristics of the component
 f. Equipment modifications
 g. Combinations of the above

(7) Ballistic missile booster cost as a function of weight, quantity, type of propellant, etc. (Separate relationships for each of the major components of the booster)

(8) High power prime radar equipment cost as a function of peak power and antenna area

Manufacturing Operation	Direct labor hours, with aluminum material taken as a base		
	Aluminum	Stainless Steel	Titanium
X	1	2	3
Y	1	5	7
Z	1	3	4

The table indicates that to perform operation "X" on the given sub-component made of stainless steel would require twice the direct labor hours necessary on a comparable item made of aluminum; operation "Y" using titanium would require 7 times the direct labor hours of a similar aluminum item; and so on.

This approach to the problem is admittedly somewhat difficult, and it cannot be carried out with a high degree of precision. But no better method has yet been developed.

Specialized Equipment

This category includes items of support equipment which are specialized to the primary mission equipment. For many future systems (especially ballistic missile and satellite systems) the cost of specialized equipment may be large. In some cases it is already the largest single element in system investment cost.

From the nature of specialized equipment, its components vary considerably from one system to another. Three examples are given in Table 8. Formalized techniques of cost estimation for specialized equipment are still in the early stages of development at RAND.

The current procedure--admittedly a provisional one--is to project specialized equipment requirements and costs for future systems on the basis of what is known about current development programs. Projections for future

Table 7

COST-ESTIMATING RELATIONSHIPS (EXAMPLES)

(1) Airframe direct labor cost per pound of airframe weight as a function of cumulative output and/or rate of output

(2) Cost per pound of airframe weight adjustment to be used in conjunction with (1) above. (This is necessary because past experience indicates that production cost per pound tends to vary inversely with the weight of the airframe.)

(3) Airborne radar equipment cost as a function of:
   a. Cumulative output
   b. Rate of output
   c. Performance characteristics (e.g., frequency, accuracy, jamability, discrimination capability)
   d. Physical characteristics (e.g., volume, number of tubes or transistors, number of stages)
   e. Combinations of the above

(4) Manufacturing overhead cost (for various classes of components) broken down into "fixed" and "variable," with the variable portion expressed as a function of rate of output, cumulative output, degree of utilization of plant capacity, etc.

(5) Material cost per pound (for various types of components) as a function of cumulative output

(6) Engineering cost (for various classes of components) as a function of:
   a. Cumulative output
   b. Peak production rate
   c. Weight of the component
   d. Slope of the direct labor progress curve
   e. Performance characteristics of the component
   f. Equipment modifications
   g. Combinations of the above

(7) Ballistic missile booster cost as a function of weight, quantity, type of propellant, etc. (Separate relationships for each of the major components of the booster)

(8) High power prime radar equipment cost as a function of peak power and antenna area

Table 8

SPECIALIZED EQUIPMENT (EXAMPLES)

(1) For a ballistic missile system:
- Launching
- Missile handling
- Control
- Checkout
- Power and pressurization
- Cabling and communications
- Special transport vehicles (mobile systems only)
- Special maintenance equipment
- Special simulation equipment (for training purposes)

(2) For a satellite reconnaissance system:
- Launching
- Checkout
- Training
- Readout
- Maintenance
- Communications tie-in network

(3) For a high performance fighter aircraft system:
- Aircraft servicing equipment
- Special trucks and trailers
- Missile servicing equipment
- Special maintenance and test equipment
- Specialized simulation equipment

systems are made by equipment category, modifying current systems data on the basis of such items as: (a) size and weight of the future flight vehicle and (b) nature and complexity of the preflight countdown and the periodic, peacetime checkouts.

<u>Other Equipment</u>

The cost of all initial equipment not included in the two previous categories is included here. This category contains such items as tactical unit support aircraft (if bought from current production), general purpose vehicles, construction equipment, materials-handling equipment, general purpose communications and test equipment, mess hall equipment, special flying clothing and similar individual equipment, and general purpose maintenance equipment.

Tactical unit support aircraft* are usually aircraft which have already been paid for and have finished their service in the first line, and are therefore regarded as cost free. However, if aircraft are bought from current production, the cost is treated as investment and is computed in essentially the same way as for primary mission aircraft.

Except for tactical unit support aircraft (and except for special cases where an estimate is built upon detail), other equipment cost is generally estimated as a function of number of military personnel. Estimating equations relating the cost of this equipment to number of military personnel for various types of combat and support organizations have been developed by RAND through detailed analyses of Air Force Unit Authorization Lists.**

---

*Examples are transports assigned to a tactical unit for logistic support and/or administrative purposes, and trainer aircraft assigned to the tactical unit for on-the-job pilot training.

**For these lists see <u>USAF Monetary Report on Unit Authorization List Equipment</u>, Directorate of Statistical Services, HqUSAF (Secret), published annually.

STOCKS

The continuing and effective operation of a system is in large measure dependent on the ready availability of certain supplies. Air Force combat and support organizations must have on hand supplies of fuels, lubricants and propellants, maintenance supplies and parts, spare aircraft engines, etc.

The costs incurred in establishing these initial inventories at the time a combat unit is formed are included under the investment category called stocks. RAND's concept of stocks is a broad one. The term is defined to mean not only initial inventories on hand with the combat unit, but also the unit's pro rata share of supplies at the Air Materiel Command depots and the supplies in the pipeline from manufacturing plant to depot.

For convenience in computation and presentation, the category has been broken down into two subcategories: initial stock level, and equipment spares and spare parts.

Initial Stock Level

This category includes items (including War Readiness Material stock, where appropriate*) such as personnel supplies, installations maintenance supplies, organizational equipment supplies, POL, propellants, etc. The size of the initial stock is a proportion of the estimated annual consumption, depending upon the number of days of consumption to be provided for as required by Air Force planning documents. Thus, if 75 days of supplies are to be on hand as initial stocks, the cost would be 75/365 times the cost of the supplies needed for one year's operation.

*See USAF Material Program Guidance, P-62-1, Vol. II, published by the Directorate of Material Programs, HqUSAF (Secret).

Equipment Spares and Spare Parts

This category includes the costs of initial stocks of spares and spare parts (including War Readiness Material stocks, where appropriate) for the following types of equipment:

(1) Primary mission equipment (e.g., missiles, aircraft, prime radar)

(2) Specialized equipment (e.g., ground support equipment)

(3) Unit support aircraft (if such aircraft are procured new)

The cost is computed by taking a percentage of the investment cost of the item of equipment to which the spares and spare parts pertain. RAND has developed appropriate percentages by analysis of USAF budget and contract data, for various classes of equipment, including:

Manned aircraft:
  Bombers
  Fighters
  Cargo and miscellaneous
Missiles:
  GARs
  GAMs
  Ballistic missiles
  Air breathing missiles
  Drones
  (For some types of missiles different percentages are used for the major components of the missile: airframes, propulsion, guidance, etc.)
Surveillance equipment
Specialized equipment:
  (Different percentages are used, depending upon the type of primary mission equipment the specialized equipment is designed to support)

INITIAL TRAINING

These costs cover:

(1) Formal training necessary to bring each man up to the level of skill required for his occupation with the new system. This includes direct costs (pay and allowances of students, pay and allowances of instructors, etc.), indirect costs (pro rata share of pay and allowances of support personnel, base support costs, training command overhead, etc.) and pro rata share of depot maintenance costs for courses using trainer aircraft.

(2) Missiles consumed in live firings during the initial training of personnel for a new weapon system. The cost of these missiles is computed by the integrated primary equipment costing method illustrated by Table 4.

A prerequisite for calculating initial training cost is the determination of personnel requirements by occupational classification (or in some cases groups of occupational classifications). For current and near-future systems, personnel requirements may be obtained from USAF Organization Tables, Unit Manning Documents and related manning documents. (The data taken from these documents may have to be adjusted if the operational concepts of the system under study differ significantly from those assumed in the documents.) For distant-future systems for which manning documents do not exist, it is necessary to build up personnel requirements from detailed examination of the system's organizational and deployment plan, alert capability requirements, activity rate, and other elements of the system operational concept. Determination of personnel requirements is a complicated problem which can only be touched on here. It is discussed in more detail in the Appendix.

The next step is to determine the initial training requirements. This may not be easy, because training requirements for a new system are often dependent upon concurrent developments in other systems. The problem is one of incremental costing.

An example will make this clear. Assume the following conditions:

(1) A new bomber system A is being phased in to the active inventory.

(2) Existing bomber system B is to stay in the force at its current level.

(3) As part of a general change in the total force structure, bomber system C and fighter system D are phasing out rapidly.

It is clear that the initial training requirements for A will not be equal to the total personnel skill levels demanded by A. Most of these skills may be obtained in varying degrees from personnel released by the rapid phase-out of C and D. Some of these personnel can be transferred directly to A without having any transition training. For such occupational specialities the initial personnel training requirement and cost to A is zero. In the case of other skill levels demanded by A, personnel being transferred to A from C and D will need transition training. The cost of this training is charged as an initial training cost to A. Finally, there will probably be requirements which cannot be met by transfer of skilled men or by transition training. The cost of producing these new skills is also charged to A as an initial training cost. But the total initial training cost for A is less than it would be if there were no transfer of skills. How much less depends primarily upon the rate of phase-out of C and D, and the extent of the carryover of skill levels from C and D to A.

But even this is not the whole story. System B has not yet been taken into account. Although B does not have an initial training requirement during the period under consideration, it does have a replacement training requirement stemming from normal personnel turnover. Much of this replacement training requirement can be met by transfer of personnel released from C and D, either at zero cost or at the cost of the necessary transition training. But the extent to which B can draw on these personnel may depend on the demands of A. If the pool of released personnel is not large enough to satisfy all demands, a priority schedule is used to determine the allocations to specific systems.

The conclusion must be that the initial training cost for a given system is best determined within the context of the total force structure. Only in this setting can the numerous interrelations among the various Air Force systems and other activities be taken into account. A further point is that initial training (an investment cost) and replacement training (an operation cost) must be estimated simultaneously--a situation analogous to the integrated costing of primary mission equipment discussed previously. After training requirements have been determined as outlined above, and the availability of fully trained personnel has been taken into account, the cost of training is estimated for each speciality by multiplying the number requiring complete or transition training by a factor representing the per man cost of the training. Where complete training is required, the cost factors are given in Air Force publications.*

For transition training, which is the more frequent case, other factors should be used, and these must often be developed by the cost analyst in the course of the analysis. Approximations to such factors for various occupational categories and groups of categories have been derived at RAND through study of the training costs per man required to produce a given skill level beginning with various levels of preparedness. The results can be expressed in the following form:

---

* See especially Peacetime Planning Factors Manual, HqUSAF (Secret).

Transition Training Cost Per Man for a Given

Occupational Category

Activity from which the Person is Transferred	Activity to which the Person is Transferred		
	A	B	$ C
D	$ 500	$1500	$2000
E	2500	1000	1000
F	1000	1500	1000

Matrices of this type are basic to the costing of training requirements. Their elements are not easy to derive, and additional data and analysis will be needed.

Although the most satisfactory way to determine training requirements and costs is by the use of an integrated estimating technique involving all the relevant systems, there are occasions when this is not practicable outside of total force structure analysis. For estimates of training costs for a weapon system considered in isolation, one of the following approaches may be used to obtain an approximation:

(1) Examine a similar weapon system recently phased in, and assume that the new system will experience a similar carryover of skills from other activities.

(2) Assume a force structure in broad outline for context purposes, and from this infer what the carryover of skills would be.

(3) For distant future systems, neither (1) nor (2) may be practicable. In such cases, it is probably best to assume that all personnel must be completely trained, and to treat the resulting cost as an upper limit.

MISCELLANEOUS INVESTMENT

This category contains the following items: initial transportation, initial travel, and intermediate and support major command investment cost.

Initial Transportation

This includes the cost of transportation of all initial supplies and equipment, except aircraft and materials used in construction of base facilities. Aircraft are assumed to be transported under their own power, and construction cost factors used to compute the initial cost of installations include an allowance for first-destination transportation.

Initial transportation cost is normally computed by the use of equations which relate the cost of initial transportation to (1) the number of military personnel and (2) the initial cost of equipment excluding aircraft. Separate estimating equations are used for aircraft, missile, and surveillance systems.

In most cases initial transportation is a very small fraction of total system investment cost, although there are important exceptions, such as the DEW and BMEWS systems.

Initial Travel

This includes the cost of transporting personnel and their dependents to the operating bases when a system is phased in to the active force.

Initial travel cost is estimated by the use of equations relating it to numbers of military personnel, different equations being used for locations in the ZI and overseas. Initial travel cost is typically a very small fraction of total system investment cost.

Intermediate and Support Major Command Investment Cost

This category includes investments made at the intermediate and support major command level which can be specifically identified with the particular system under consideration. Examples are the following:

(1) The initial cost of simulation equipment (including initial spares) to be used by the Air Training Command in direct training support of a given system.

(2) The initial cost of primary mission equipment (including initial spares) to be used by the Air Training Command in direct training support of a given system (e.g., the F-102s assigned to the ATC to support the F-102 program, both for initial and replacement training.)

(3) Investment in new equipment and/or facilities at Air Material Command for depot maintenance support of a given system.

Except for costing of equipment, the techniques for costing items in this category are largely *ad hoc*, making use of all the relevant information available at the time. In the case of investments at AMC, for example, such documents as *Depot Maintenance Facilities Planning Guide* and *AMC Program Guidance* may be helpful. In this category, projections into the distant future are necessarily rather crude.

Operation Costs

Operation costs are those recurring annual outlays which are needed to operate and maintain USAF activities after they have been initiated into service.

Our analysis deals with these costs in seven major categories, which are discussed below.

EQUIPMENT AND INSTALLATIONS REPLACEMENT

Primary Mission Equipment

The cost of annual attrition of primary mission equipment is accumulated under this heading. Attrition rates and methods used to compute annual replacement requirements depend upon the type of equipment under consideration. For manned aircraft, replacement requirements are determined

on the basis of the flying hour attrition rates contained in the Peacetime Planning Factors Manual.

For most missile systems, the attrition problem is considerably different from that for manned aircraft. For ballistic missiles deployed in underground silos in a constant state of readiness, certain components (e.g., gyros) may be in continuous operation or exercised frequently for checkout purposes while other components (e.g., solid rocket motors) are left untouched for prolonged periods of time. Naturally, significantly different replacement rates may be expected for components depending upon how actively they are used in maintaining alert status. It is desirable therefore to estimate missile attrition at the component level, giving considerable attention to the effect of plans for alert status. Data on attrition rates of components (airframes, guidance, power plants) should be sought from contractor estimates of the lifespan of components under system operating conditions.

The costing of primary mission equipment replacements is accomplished by the integrated equipment costing method discussed previously. It should be noted that the cost of equipment replacement is computed only for as long as the equipment is scheduled to be in production for the Air Force. After that time, attrition continues but replacement does not take place and there is no replacement cost.

Specialized Equipment

The annual replacement cost of specialized equipment is computed by taking a percentage of the initial investment cost of the specialized equipment. These percentages are derived from analyses of historical attrition data for numerous types of specialized equipments and from

contractor estimates of average service life for various future equipments.

Other Equipment

This category includes the cost of unit support aircraft and other equipment in general. The unit support aircraft portion of the category is treated in the following manner. As indicated previously, these aircraft are often second line aircraft already paid for and hence cost free in relation to the new system. However, if these aircraft are bought new, annual attrition cost for unit support aircraft must be computed as long as the aircraft continue to be purchased by the Air Force. The computation is done in essentially the same manner as for primary mission equipment.

The remaining other equipment annual costs are estimated by taking a percentage of the initial investment cost of the equipment. The replacement percentages used in RAND were developed from analysis of USAF accounting reports, such as the AF C-100 Expense Report, HqUSAF.

Installations

This category provides for replacement (in kind) of worn out base facilities. The cost is determined from equations which relate cost to number of military personnel and geographical location. Separate equations are used for manned aircraft, missile, and surveillance systems. A distinction is made between tenant and non-tenant organizations.

MAINTENANCE

Primary Mission Equipment

This category represents the annual cost of materials used at base

and Air Materiel Command depots for the maintenance of a unit's primary mission equipment, plus the cost of labor at the depot level. (Payroll cost associated with base maintenance is included in the pay and allowances cost category.) If depot maintenance is performed by a contractor, contractor maintenance is substituted for AMC depot maintenance in this category.

For manned aircraft systems, maintenance cost is usually estimated as a function of flying hours, based on the cost factors for various types of aircraft given in the Peacetime Planning Factors Manual.

Missile maintenance cost is estimated as a percentage of the initial investment cost of the primary mission equipment. Percentages for this purpose have been derived from analysis of maintenance cost data for missile systems currently in operation. Separate maintenance cost factors have been developed for the major components (airframe, power plant, and guidance) of various types of missiles.

Surveillance system maintenance cost is also estimated as a percentage of the initial investment cost of the primary mission equipment. Percentages were derived from an analysis of radar maintenance cost data obtained from the Rome Air Materiel Area of the Air Materiel Command.

Specialized equipment

Maintenance cost for specialized equipment is computed as a percentage of the initial investment cost of the equipment. Percentages for various types of equipment have been developed at RAND from studies of historical maintenance cost data for various types of specialized equipment.

Other Equipment

The main item here is the maintenance cost for unit support aircraft. It is computed in the same manner as for primary mission aircraft. (The maintenance costs of remaining "other equipment" are included under major Category F, "Services and miscellaneous.")

Installations

These costs represent the materials and contractual services required for maintenance of the unit's base facilities. Pay of military personnel associated with installations maintenance is not included here but is accumulated under the pay and allowances category.

Installations maintenance cost is computed from estimating equations which relate maintenance to the initial investment cost of base facilities, to the number of military personnel, and to geographical location. Equations have been developed for manned aircraft, missile, and surveillance systems, and for tenant and non-tenant organizations. These estimating functions were derived from an analysis of USAF cost reports, e.g., AF C-100 Expense Report.

TRAINING

Annual training cost is made up as follows:

(1) The cost of training replacements for personnel leaving an Air Force unit because of discharge, resignation, return to inactive status, etc.

(2) The cost of any missiles and fuel consumed in periodic live firings for training purposes. (Missiles are costed by the integrated procedure previously described.)

The gross replacement training requirements are computed on the basis of current USAF personnel turnover rates, separate rates being used

for airmen, pilots, other rated officers, and other officers. Gross requirements should, if possible, be reduced to net requirements by taking into account the transfer of partly or completely trained personnel from other USAF activities. The procedure is the same as that previously described for initial training requirements.

PAY AND ALLOWANCES

This category includes basic pay (including longevity), cash subsistence allowances, cash quarters allowances, general officer personal money allowances, hazard pay, maintenance clothing allowance, overtime and cost-of-living allowances for civilians, dislocation allowance, retirement deductions, and income taxes withheld, plus a supplemental cost which includes lump-sum payments, FICA charges, subsistence, permanent change of station travel, and temporary duty travel for military personnel.

The cost of pay and allowances is determined by applying appropriate factors to the numbers of personnel of various type required by the unit. Separate sets of factors, one for the ZI, another set for overseas locations, have been developed for civilians, rated officers, other officers, crew airmen, and other airmen.

These factors were derived from an analysis of budget data obtained from USAF budget justification documents.*

FUELS, LUBRICANTS, AND PROPELLANTS

Primary Mission Equipment

For manned aircraft systems the annual cost of fuels and lubricants

---

*For example, Department of the Air Force, Justification of Estimates for FY 1960, January 30, 1959.

is estimated as a function of flying hours on the basis of factors (POL cost per flying hour) obtained from the Peacetime Planning Factors Manual. For distant-future systems these factors must be adjusted to allow for the performance characteristics of the future aircraft. In some cases, estimates of fuel consumption rates may be obtained from the technical specifications of the system, and these may be costed on the basis of current or projected fuel and lubricant prices as appropriate.

For missile systems where the fuel is not an integral part of the missile, the total annual fuel and oxidant requirements are determined on the basis of missile capacity plus estimated transfer and evaporation losses.

For conventional surveillance systems, annual fuel and lubricant cost is estimated as a percentage of initial primary equipment cost. This percentage was derived from an analysis of aircraft control and warning site operation costs obtained from Headquarters USAF and Air Defense Command cost reports. For advanced systems other techniques must be used, e.g., fuel and lubricant cost may be estimated as a function of power requirements or environmental control requirements.

Other Fuels, Lubricants and Propellants.

This category includes the cost of fuels and lubricants for unit support aircraft, computed in essentially the same way as for primary mission aircraft.

SERVICES AND MISCELLANEOUS

This category includes a large number of small items of operation cost, the aggregate of which is typically a small proportion of the total

annual operation cost for a weapon or support system. Since the aggregate cost is relatively small, it is estimated by major component only, using gross estimating methods. In most cases the cost factors used by RAND were obtained from analyses of USAF budget and cost report data.

Transportation

The annual transportation charge includes the cost of transporting to the base the replacement equipment and the supplies consumed during that year. It is estimated as a function of number of military personnel and of the total cost of equipment maintenance. Separate estimating relationships have been developed by RAND for ZI and overseas locations.

Travel

The annual operation cost for travel represents an allowance for cost of transportation of military personnel and dependents incident to normal peacetime turnover. It is computed on the basis of factors (separate ones for the ZI and overseas) relating annual travel cost to number of military personnel.

Other Services and Miscellaneous

This category includes annual operating and maintenance costs not included in any of the other categories. An attempt is made to take into account the cost of materials, supplies, and contractual services for such functions as base administration, flight service, supply operations, food and medical services, and operation and maintenance of organizational equipment. These costs are estimated as a function of number of military personnel. Separate estimating relationships have been developed (for both the ZI and overseas) for contractual services, materials and supplies.

and ammunition.

INTERMEDIATE AND SUPPORT MAJOR COMMAND OPERATION

Generally speaking, these costs are considered only in total force structure analysis and discussion of them will therefore be postponed to Chapter III. Exceptionally, it may be desirable to include costs of this category in individual system analysis; for example, in relation to certain SAC systems, the operation cost of air division headquarters is assigned to a weapon system if the headquarters is closely related to the system.

Research and Development Costs

According to the logic of our division of costs, this category must include **all** the costs necessary to bring a system into readiness for introduction into the active inventory. To avoid possible confusion, it should be pointed out that this usage is considerably broader than some of the specialized meanings conventionally associated with the phrase in an Air Force context. For example, the Air Force "Research, Development, Test and Evaluation" (600-money) budget category provides for slightly over $1 billion in fiscal year 1961, whereas the broader usage adopted here shows a cost of close to $3 billion for the same period.* This larger sum reflects the inclusion of costs from other budget categories which can be properly identified with Air Force research and development activities. These include research and development shares of costs for procurement (100-, 200-, and 800-money), construction (300-money), operation and maintenance (400-money), and military personnel (500-money).

*Both of these sums include costs of non-systems research and development activities, and refer to the total force. Our usage is the more inclusive for both individual system and total force costs.

The cost of research and development has increased during recent years because of the demand for major technological advances in each new generation of weapon systems and also because of the heavier consumption of flight test vehicles in missile and space system development compared to manned aircraft development. A ballistic missile makes only one test flight while a series of flights can be expected for each experimental aircraft fabricated.

Concurrent with increased spending for research and development, the size of operational forces has tended to decrease, and thus as a proportion of total weapon system cost, research and development has taken on a new importance. In addition, an increasing number of weapon systems are either developed and never put to operational use (e.g., Navaho and Goose) or phased out after very limited operational procurement (e.g., Snark and Jupiter). The increasing length of time required for weapon development, the accelerated rate of technological progress, and the nature of our competition with the Soviets, have all contributed to unexpectedly early project termination.

The implications for military budget management and programming are clear. Better and longer-range research and development cost estimates are needed both for evaluating individual weapon system proposals and for estimating the funding requirements of projected total force structures.

A word of caution is in order at this point. The nature of research and development makes the cost-estimating task a difficult one. The existence of a research and development program itself implies that a proposed system is expected to have a previously unattained performance level or a combination of properties never before incorporated in a single

system. Its final configuration and perhaps even its successful development are uncertain. The design, the methods of fabrication, and the manpower, material, and facility requirements cannot be described precisely at the time a project is started. All these uncertainties indicate the need for analysis to produce, not a single figure, but a range of reasonable values.

Table 9 displays the major categories used at RAND for analysis of research and development costs. The structure shown is intended for systems built around an aerospace vehicle, but it is adaptable for electronic command and control and other support systems. Basically, the table distinguishes between system costs (Categories I, II, and III) and non-system costs (Category IV). The latter are dealt with as part of total force cost analysis, and detailed discussion of them can be found in Chapter III.

SYSTEM DEVELOPMENT

This category often represents a sizable share of the total research and development cost of the system, especially if substantial advances in technology are required. Generally, the amount of design work, the number of breadboard models and mockups, and the number of tests which may be required before an acceptable configuration is achieved, cannot be estimated in advance with great precision. Although it is helpful to divide the category into the three sub-categories listed in Table 9, in practice our techniques are not yet sufficiently refined to enable us to cost each separately. This category is usually costed as a single item, the estimate being based on analogy with similar systems developed in the past.

The use of analogy requires, of course, suitable records of weapon and support system research and development costs structured in accordance

Table 9

RESEARCH AND DEVELOPMENT COST CATEGORIES

I. System Development

A. Preliminary study and design.

B. Design engineering: the scientific and engineering services conducted within a contractor's own facilities, including development testing of sub-systems and combinations of sub-systems. For a ballistic missile development program this includes design and development work on all sub-systems, together with special instrumentation and ground equipment for launch, checkout, and control. Wind tunnel, structural, environmental, and reliability tests may be needed.

C. Hardware fabrication: breadboard models, mockups, and special test articles; special jigs, dies, fixtures, and other tooling required primarily for development and development testing.

II. System Test and Evaluation

A. Vehicle fabrication: the complete system produced for the test inventory; equipment spares; and pro rata shares of new industrial equipment and facilities required for plant expansion.

B. Captive test operations.

C. Flight test operations: including fuels and propellants used; data reduction, analysis, and reporting.

D. Test equipment: such as launchers, checkout consoles, handling devices, guidance and computer systems for use at test sites; instrumentation; and equipment spares.

E. Installations: design and construction of test facilities.

III. Other System and Development Costs

A. Depot maintenance and supply support.

B. Miscellaneous.

IV. Research and Other Non-System Activities (used in total force cost analysis)

with Table 9, together with detailed descriptions of the systems. The selection of an appropriate analog requires more than hardware similarity. Such considerations as the following should be in the analyst's mind: How many components require substantial advances in technology, and to what degree? Is the development a "crash" or a more routine program? Are any special management arrangements required?

These considerations suggest the extent to which the estimation of system development costs is a subjective procedure. One quantitative guide is the "engineering-hour" requirement. Although the definition of this requirement varies from contractor to contractor, the data can be interpreted by the analyst to provide an index of development costs or to assist him in adjusting the costs of analogous systems. Engineering-hour data should therefore be included wherever possible in the analyst's library of information.

SYSTEM TEST AND EVALUATION

The subcategories listed under this heading can be estimated separately, and we have developed somewhat formalized techniques for this purpose. The result is a total cost estimate for the category which can be more generally relied upon than the estimate of system development costs.

The method for estimating the cost of test vehicle fabrication is very similar to that used in estimating the cost of units intended for the operational inventory. In fact, in the current ballistic missile programs, operational and flight test items are fabricated side by side as members of a given production lot. Derivation of the cost of vehicles intended for either application requires preparation of an improvement curve for all the units produced up to any given quantity. Test vehicles usually

require telemetering and other data recording devices not included in the operational hardware. The cost of this test equipment is borne by the Air Force and must be included in any estimate of total flight hardware requirements.

The costs of captive and flight test operations are separately estimated on a "per-flight" basis, with unit costs derived from data for analogous systems the actual costs of which are already known. Care is taken to account for the effects of such things as more or less crowded test ranges, differences in test-crew experience, and changes in test procedures and test instrumentation.

The costs of test equipment and installations depend critically upon the availability of usable facilities already in existence. Cost analysis therefore requires current information about the probable future availability of facilities and the costs of various kinds of modification.

Table 10 provides a useful format for assembling a library of cost data about existing test facilities--in this example, for missile test facilities. The same format may be used for in-plant, static, flight, and operational suitability test sites. Basically, it shows support equipment and installation requirements, broken down by major type and by location. In our experience, analysis of location is helpful in avoiding errors of omission. Most of the errors which are likely to arise in estimating costs of weapon system ground environments, both for test and for operational use, derive from underestimation of requirements rather than from mistakes in the costing of designer-specified items. Completeness of the requirement can be checked by a comparison of systems on a site-by-site basis.

Table 10 is, however, only a summary. Much additional information,

Table 10

TEST FACILITIES: FORMAT FOR RECORDING BASIC DATA ON

EXISTING INSTALLATIONS AND GROUND SUPPORT EQUIPMENT

Type of Equipment	Location: Launcher (A)	Location: Launch Control Center (B)	Location: Maintenance Area (C)	Location: Mobile & General (D)	Total by Type of Equipment
Test Ground Support Equipment:					
1. Launch & missile handling					
2. Control & checkout					
3. Power & communications					
4. Miscellaneous					
Total test GSE					
Test Installations:					
1. Structures					
2. Service utilities					
3. Ways & fences					
4. Miscellaneous					
Total test installations					
TOTAL (by location)					

both cost data and descriptive material, should be obtained and recorded for each numbered element, as is shown in outline in Table 11. Information about the physical characteristics of launch and missile handling equipment, the load-bearing capacity of launch pads, and the data-processing capabilities of control and checkout gear, is likely to be particularly useful in forecasting the requirements of new systems.

OTHER SYSTEM RESEARCH AND DEVELOPMENT COSTS

Costs in this category are currently being estimated as a percentage of the total of Categories I and II in Table 9.

Table 11

TEST FACILITIES: SUPPLEMENTAL INFORMATION

I. Examples for Test Equipment (Ground Support)

1(A) 1. Hold down and launch assembly
2. Support and erection mechanism

1(C) 1. Alignment gage for the missile
2. Cradle assembly for the booster section

1(D) 1. Trailer for booster handling
2. Missile semitrailer

2(A) 1. Control unit for the electrical purge system
2. Automatic pilot control group
3. Control unit for special tank pressurization

2(B) 1. Recorder group
2. Panels and consoles
3. Fault location unit

2(C) 1. Test sets
2. Relay test programming kits
3. Automatic programmed checkout equipment

2(D) 1. Mobile telemetering checkout equipment
2. Trailerized maintenance checkout equipment

3(A) 1. Power supply assembly
2. Power distribution unit
3. Hydraulic pumping unit

3(B) 1. Electrical equipment cabinet
2. Power supply

3(C) 1. Transistor power supply
2. Klystron tube
3. Nitrogen charging panel assembly
4. Hydraulic pumping unit

3(D) 1. Power distribution trailer

4(A) 1. Umbilical cable kit
2. Interconnecting cable kit

4(B) 1. Distribution unit cable
2. Interconnecting cable kit

4(C) 1. Special checkout cable kit
2. Checkout distribution unit cable

4(D) 1. LOC to launcher interconnecting cable kit

II. Examples for Test Installations

1(A) 1. Launch pad
2. Long duration flame deflector

1(B) 1. Control center blockhouse

1(C) 1. Maintenance and storage buildings

2(A) 1. Water lines
2. Wash-down hydrants and lines
3. Electrical distribution

2(B) 1. Water distribution
2. Electrical distribution

2(C) 1. Water distribution
2. Electrical distribution

2(D) 1. Power substation
2. Water mains, etc.

3(A) 1. Sidewalks

3(B) 1. Parking areas
2. Sidewalks

3(C) 1. Parking areas
2. Sidewalks

3(D) 1. Fences
2. Roads
3. Gate facilities

CHAPTER VII

COST ANALYSIS OF TOTAL FORCE STRUCTURES

In our discussion of cost analysis for individual systems, we have already touched on problems which required the particular system to be treated in relation to other systems and non-system activities. A new system may use base facilities already in being, it may employ personnel already trained, and it may embody the results of basic and applied research carried out by the Air Force without reference to specific systems. In this chapter we take these relationships explicitly into account.

In its more general sense, total force cost analysis refers to the costing of many different "mixes" or combinations of systems and non-system activities, so that the total costs of various real or hypothetical force structures can be compared. In addition to its inclusive character, total force cost analysis emphasizes the specific timing of requirements for funds and other resources. In its more limited sense, total force cost analysis refers to the costing of particular systems in the context of a force structure otherwise more or less fixed. The cost of a system thus becomes a marginal cost--the change in the total cost caused by the addition of the system to the force structure.

FORCE COMPOSITION AND ASSUMPTIONS

Total force composition is expressed in terms of the number of squadrons (or other appropriate unit) at the end of the fiscal year for each of the weapon and support systems making up the total structure. As in individual system cost analysis, a prime objective is to identify with each system the costs of all the activities generated by it.

Physical specifications of systems, numbers of squadrons, etc., are only part of the data required. In addition there are the kinds of information which we have referred to earlier as concept specifications or "assumptions." Differences in assumptions (e.g., about live-firings in missile training) can lead to very large differences in cost estimates. Assumptions include information about concepts of system deployment, training, and operation. In total force analysis, they also include relevant information about mission and Air Force organization and policies.

In dealing with the total force, the analyst must draw upon a much wider universe of information than for individual system cost analysis carried out in isolation. In addition to the references mentioned already, there is a series of basic documents which deserves the analyst's special attention. These are the "principal program documents" described in Air Force Manual No. 27-1, USAF Program Process,* and in particular those on Program Guidance; Base Utilization and Major Deployment; Aircraft, Missiles and Flying Hours; Manpower and Organization; and Communications-Electronics.

INCREMENTAL COSTING AND LONG-TERM PROGRAMMING

Total force cost analysis aims at incremental costing in its fullest sense. The availability of existing resources is taken into account in estimating the additional resources required to add a new system to the force. Changes in the existing force structure (for example, the phasing-out of a weapon system) may make resources available for new systems being phased in. These resources may be of any kind, but especially important are trained or partly trained personnel, and installations and equipment

*Department of the Air Force, Air Force Manual No. 27-1, USAF Program Process (1 May 1958), Chapter 3.

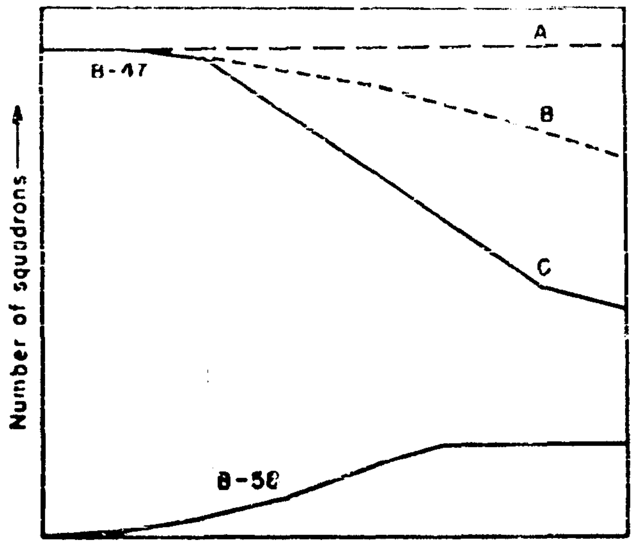
usable directly or after modification. In total force cost analysis, all resources are taken into account simultaneously as well as all the systems and other activities which are competing for these resources.

Figure 3 illustrates this principle in the simple case of two systems which (we will assume) can make use of the same bases, crews, and other resources. B-47 squadrons are part of the existing force, and B-58 squadrons are being phased in. Figure 3a shows three hypothetical patterns of B-47 phasing. Curve A corresponds to a constant number of B-47 squadrons during the whole period under consideration. Curve B corresponds to a gradual phase-out of B-47's, and curve C to a rapid phase-out. The curve at the bottom of the chart shows a hypothetically programmed phase-in of B-58's.

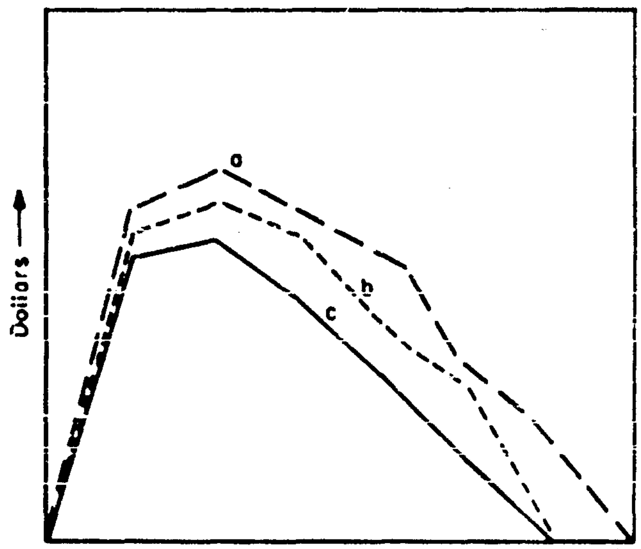
Figure 3b shows the associated time-phasing of investment costs for the B-58 system. Curve a (corresponding to curve A) is the upper limit of costs, with all bases having to be built from the ground up, all personnel having to be trained from the beginning, etc. Curve b illustrates costs with B-47 bases available for modification, but crews requiring full training. Curve c illustrates costs with maximum carryover of resources: bases available for modification and crews requiring only transitional training. Aircraft, ground equipment, and stocks are therefore the main elements of cost represented by curve c.

Total force cost analysis provides for incremental costing by establishing a framework within which all the resources available and the needs of the various systems can be considered simultaneously at successive intervals of time.

In practice, the fiscal year is the unit of time employed, and



3a



3b

Fig.3a—3b—Incremental costs and phase-in phase-out relationships

estimates are developed for each fiscal year of the programmed period. The period considered is usually a long one--5 or 10 years or more--because of the long "lead-time" required for the development and procurement of modern systems. It now takes some 5 to 10 years or more to move from idea to operational hardware.* Long-range planning and programming of systems must therefore take such periods into account. In the Air Force, long-range plans and programs often cover a period of 10 years or more.

COSTS AS EXPENDITURES AND AS PROGRAM REQUIREMENTS

Costs may be looked at as actual payments of money or as the authority to incur obligations to pay. The former are expenditures; the latter is "obligational authority." Obligational authority is required before a procurement contract can be entered into on behalf of the government. These two kinds of costs normally differ in timing, especially with respect to procurement of long lead-time items. The distinction is usually not of great significance in comparing individual weapon systems, but it is important in considering the financial implications of total force structures, because the expenditures involved are a large share of all government expenditures. In recent years expenditures have assumed an increased importance largely because the national debt has pressed close against its legal limit, thus reducing the government's financial flexibility, and making it necessary for expenditures and cash receipts to be kept in near balance.

Obligational authority is important because it is the form in which

*See David Novick, "Lead-Time in Modern Weapons," The RAND Corporation, Paper P-1240, December 26, 1957.

Congress approves the Air Force budget. The total obligational authority desired by the Air Force each year for each of its "programs" is called the "program requirement." This program requirement consists of new obligational authority asked of Congress, plus that obligational authority carried over from prior years which is available for current use in funding new programs, plus reimbursements for certain items.

In programming for future years, it is the total obligational authority we are interested in rather than a breakdown between new obligational authority, old authority carried over, reimbursements, etc. For this reason we will refer to program requirements rather than to obligational authority. In our method of total force cost analysis, cost estimates are treated specifically as program requirements (total obligational authority to be available during the fiscal year) and as expenditures (cash outlays to be incurred during the fiscal year). The former precede and generate the latter.

A time schedule of the physical resources to be acquired by the Air Force is stated in terms of equipment delivery dates, installation beneficial occupancy dates, squadron activation dates, etc. These "activity dates"* are preceded by the related program requirements and are both preceded and followed by the related expenditures. For example, a base scheduled for beneficial occupancy in 1964 might require contracts to be let in 1961 and 1962 and expenditures under these contracts during four or five successive fiscal years. Figure 4 illustrates this relationship diagrammatically. The total installation cost is approximately the same

*This term, not officially adopted in USAF usage, is used here because of our need for a more general term than "activation date." In electronic data processing, "activity dates" are often referred to more simply as "deliveries."

in terms of both program requirements and expenditures, but the yearly incidence of cost is different.

Figure 4 illustrates the financial history of a single installation. The total force consists of many installations, systems, etc., in various stages of their history, some requiring heavy investment, others being phased out and requiring only relatively small operating expenses. In any given fiscal year there will be a number of costs incurred on behalf of activities whose usefulness lies in the future. This is true not only of research and development and training, but also, as shown in Fig. 4, of such things as conventional installations.

Some early estimates of total force costs were characterized by diminishing fiscal year totals in the latter years of the projected program, as shown by the solid line in Fig. 5. This false picture was produced by ignoring activity dates which lay in the future beyond the period of analysis, but which would already be generating expenditures before the period ended. The unreality of such estimates was accentuated in the case of program requirements, for these precede activity dates more than actual expenditures do. The solution adopted at RAND is to extend the period of analysis to include activity dates several years beyond the latest year for which a realistic estimate is needed. A typical result is indicated by the dotted line in Fig. 5. Generally an extension of two or three years is sufficient for investment and operation costs, but, because of the long lead time involved, a longer period is often desirable in estimating innovation costs.

From what has already been said, it should be clear that when we speak of the cost of a total force structure, we generally have in mind,

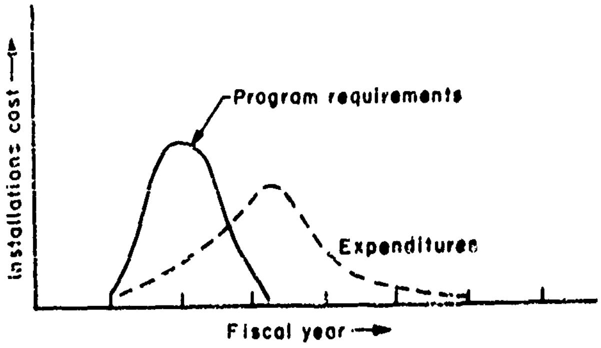


Fig.4—Timing of program requirements and expenditures

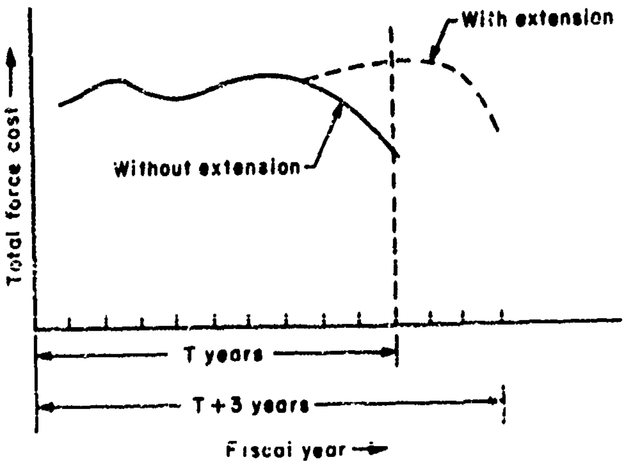


Fig.5—Extending the period of analysis

not a lump-sum of some kind, but a fiscal year cost which includes all expenditures (or all program requirements) for the year. The costs of alternative total force structures are compared in terms of their fiscal year costs over a period of years. For the Air Force, this includes not only the costs of the strategic, tactical, and defense missions, and such activities as the Air Research and Development Command and the Military Air Transport Service; it also includes all other Air Force costs: the total of the resources which the nation allocates yearly to the Department of the Air Force.

In comparing individual systems, it is primarily the relative cost of the systems which we look to in choosing between them. But the cost of the total force has importance as an absolute figure. For practical reasons, large annual variations in the total force cost are not encouraged, and it is therefore necessary to program for a balance of research and development, investment, and operation costs, the sum of which will remain fairly stable from year to year and will conform to the projected budget limitations.

MISSION AND OTHER LOWER-LEVEL COST ANALYSES

Between the individual systems on the one hand, and the total force on the other, we may distinguish an intermediate grouping, that of the major missions of the Air Force: strategic, defense, and tactical. Certain non-system activities, such as SAC Headquarters, which are closely identifiable with a major mission, are combined with the appropriate weapon systems to make up the total cost of the mission.

Non-mission activities such as those parts of support major commands (Air Material Command and Air Training Command, for example) which cannot

be allocated to systems or missions, are also analyzed and the costs estimated. Thus totals are provided for each weapon or support system, for each mission, for all non-mission activities, and for the Air Force as a whole. Total force cost analysis also makes possible the cross-classification of costs, so as to provide subtotals for specialized support activities such as logistics and training, and for the major budget series or appropriation "programs."

Users of cost estimates frequently have need of analyses at the mission level or other level or grouping below the total force. Figure 6 depicts schematically the relation between such an analysis and the total force cost analysis which is its context. In some cases a suitable total force cost analysis will be already available, so that the lower-level analysis may be accomplished by selection and cross-classification. But if a suitable total force cost analysis is not available, both the portion of the force under study, and the balance of the total force, are specified and extended for several years beyond the period under study.

SENSITIVITY, TIMELINESS, AND CLARITY

In emphasizing their inclusiveness we should not lose sight of the fact that total force costing methods must be sufficiently refined to reflect the cost implications of significant changes in structure. And these changes are not only materiel changes. Very important are changes in the assumptions about deployment, dispersal, alert status, activity rates, training, manning, logistics, etc. While sensitivity is required, it cannot be bought at the price of an extremely detailed analysis. For one thing, great detail is impossible for estimates extending 5 or 10 years into the future. For another, too much detail will slow up the progress

Fig. 6

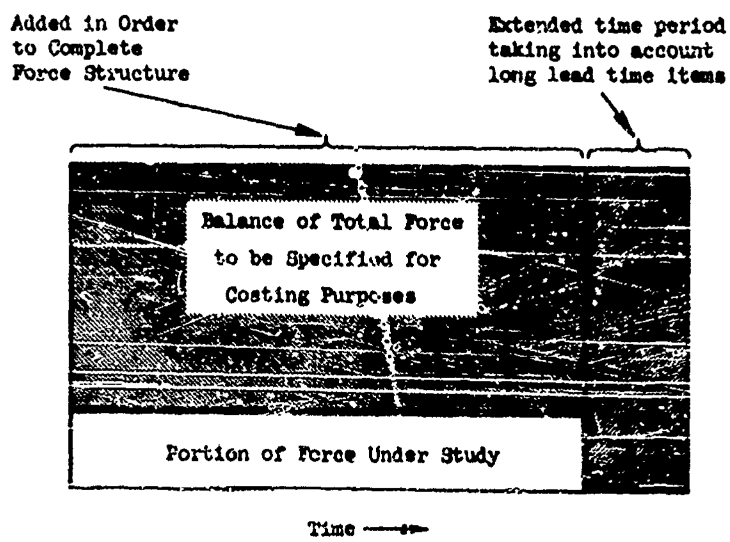
Mission Cost Analysis as Part of Total

Force Cost Analysis

Example

Study: Strategic Forces for five years

Costed: Total Force for eight years



of the analysis and make it impossible to provide estimates when they are most needed. A method of analysis which requires two or three months for calculation of a single cost estimate is inadequate for most Air Force needs. What should be aimed at is a method which will enable the analyst to produce estimates within a much shorter time and will enable changes in already costed force structures to be estimated in a day or two.

Simplification and mechanization are important aids to rapid estimation. The cost model must be simpler than the real world if procedures are not to be encumbered by the mass of detail involved in a force structure calculation. On the other hand, too great simplification will result in cost models which are too insensitive for meaningful use. The solution is to be found in generalized cost estimating equations and statistical techniques rather than a mechanical "bookkeeping" approach. Even so, a great deal of bookkeeping and detailed calculation are involved, and a high degree of mechanization is required. For this purpose a large-memory, high-speed, digital computer is employed at RAND.

The computer printouts provide a wealth of information which must be summarized and presented in a suitable manner. From the beginning the methods used should aim at the production of results significant in themselves and easily interpretable. Estimates should be accumulated in such a way as to facilitate presentation in terms of fiscal years, missions, systems, appropriation costs, and cost categories and their principal elements. So important is the method of presenting results that we devote a chapter to it later on.

COST CATEGORIES RECONSIDERED

In total force cost analysis the basic cost categories used are the

same as those described in Chapter II for individual weapon systems, and the costing of sub-categories is carried out in very much the same way. Some differences may exist because of the greater use of electronic data processing in total force cost analysis, but the principles are the same. Many of the key inputs are hand-calculated, however, and the computers only "bookkeep" the results.

Up to a point, the total force cost is an aggregation of the costs of individual systems, calculated in such a way as to take into account integrated procurement and interrelations among systems. In addition, total force cost analysis takes into account and provides cost estimates for the elements of supporting systems and non-system activities which do not enter directly into system costs. We will discuss these here, following the pattern outlined above in Table 2, beginning with investment.

Investment Costs: Intermediate and Support Major Commands

Intermediate command investment costs include such things as SAC radar evaluation and electronic countermeasures units. These are charged to the strategic mission as a whole rather than to individual systems.

Support major command investment costs include such things as (1) the initial cost of the U. S. Air Force Academy and new facilities there and at the Air University; (2) the initial cost of new trainer aircraft (and related initial spares) assigned to the Air Training Command for general Air Force training; and (3) the initial cost of new general purpose storage facilities at AMC depots. All of these are charged as investment costs to the Air Force as a whole.

Operation Costs: Intermediate and Support Major Commands

The intermediate command cost category includes (1) the headquarters

of air divisions and numbered Air Forces; (2) the headquarters of tactical major commands (e.g., SAC, ADC, TAC, USAFE); and (3) various noncombat organization which serve a tactical major command as a whole (e.g., personnel processing squadrons, radar calibration units, and statistical services squadrons). The cost of intermediate command operation is computed as an entity for each of the major Air Force missions. For example, the operation cost of the intermediate command structure in SAC, together with the operation cost of SAC overseas support, is allocated to the strategic mission. (One exception to this has already been mentioned: a SAC air division headquarters which is directly related to a particular weapon system has its operation cost allocated to that system.)

Intermediate command operation costs are computed from estimating equations which relate the costs of personnel, supply, and contractual services to the projected number of personnel in the various commands, and relate the costs of equipment operation to projected activity rates (e.g., flying hours for aircraft).

The support major command cost category includes the Air Materiel Command (excluding depot maintenance costs charged to systems) and the Air Training Command (excluding training costs charged to systems). It also includes Headquarters USAF, Headquarters Command, Continental Air Command, USAF Security Services, Air University, U. S. Air Force Academy, Air Force Accounting and Finance Center, and Air Reserve and Air National Guard programs. (MATS is not included, because it is treated as a separate "mission"; ARDC is not included because its costs are charged to research and development.)

For computation purposes, support major command operation costs are

divided into five sub-categories each of which is estimated separately. Generally the total cost for each category is computed from estimating equations derived from analysis of observed variations in operation costs as related to changes in force size, composition, rate of activity, etc.

(1) Total AMC depot maintenance operation cost is estimated as a function of total USAF fuel consumption and average missile stocks by fiscal year. From this total, the depot maintenance costs computed directly for individual weapon and support systems are subtracted, and the difference is treated as a USAF-wide, "unallocated" support major command operation cost.

(2) Other AMC operation costs are estimated as a function of total projected USAF manpower and estimated annual consumption of centrally procured supplies. On the same basis AMC operating costs are distributed to: (a) individual weapon and support systems, and (b) the support major command part of the Air Force. Item (a) represents the estimated AMC operating cost associated with the procuring, storing, and distributing of the supplies consumed by the various weapon and support systems in carrying out their mission during a given fiscal year. Item (b) may be interpreted similarly for the support major command part of the Air Force, and hence is treated as a USAF-wide "unallocated" operating cost.

(3) Total annual operating costs of the Air Training Command are computed on the basis of number of estimated flying and technical graduates required per fiscal year to support the given force structure under consideration. Allocation of these costs to weapon and support systems and to the support major command part of the Air Force is made on the same basis. Again, the ATC costs assigned to the support major command area are treated as an unallocated item.

(4) Operating costs pertaining to the Air National Guard (ANG) and Air Reserve (AR) programs are estimated primarily as a function of numbers

of personnel and flying hour programs projected for these activities. The ANG and AR costs so estimated are allocated to the defense, tactical, or MATS mission areas (but not to systems within these areas) on the basis of the mission composition of the projected ANG and AR force structures.

(5) All "other" support major command costs (Air Force Accounting and Finance Center, Air University, Hq. USAF, etc.) are estimated on the basis of current USAF projections of manpower for these activities,* except the Air Force Accounting and Finance Center which is estimated as a function of projected total USAF military personnel. None of these costs are allocated to weapon or support systems or to combat mission areas.

Research and Development Costs: Research and Other Non-System Activities

At this point it is helpful to refer to the Air Force research and development program structure summarized in Table 12.

In terms of these program structure codes (which should not be confused with budget codes), categories I, II, and III of Table 9 refer collectively to development activities coded 100, 200, and 300 (weapon systems), and 400 (control and support systems). Category IV--which we are concerned with here--refers to research and other activities coded 500, 600, 700, 800, and 000.

The Advanced Development Program (code 600) illustrates a special problem, for it includes "Advanced Systems." While an advanced system (such as CANAL or DYNA SOAR) is by definition not part of the current operational system development program, it may be transferred to this program in the future. If this transfer is expected to occur during the period covered by an analysis, the advanced system is treated as if it were a system and so far as possible is costed like one. In the same way

*For instance, see USAF Program, Manpower and Organization, PM-6[illegible]-1, published by HqUSAF (Secret).

Table 12

AIR FORCE RESEARCH AND DEVELOPMENT
PROGRAM STRUCTURE (SUMMARY)

Program	Code
Operational Developments	
Strategic Systems	100
Air Defense Systems	200
Tactical Systems	300
Control and Support Systems	400
Operational Support	500
Advanced Developments	600
(Including Advanced Systems, Test Instrumentation, and Development Support)	
Research	
Applied Research	700
Basic Research	800
Command Operations	000

Source: Air Force Regulation No. 80-9, "Research and Development Program Structure," 27 July 1959.

innovations which are not yet part of either the operational or advanced development program might properly be regarded as "systems" in research and development cost estimating studies extending 10 or 15 years into the future. A manned lunar base might be an example.

The Control and Support Systems Development Program (code 400) also presents a problem, for it includes a multiplicity of relatively less costly system developments. In principle these can be costed as individual developments, using the methods described in the last chapter, and we are beginning to do so for the more costly of them. In practice, however, in total force cost analysis, we have costed the Control and Support Systems Development Program as a single aggregate, using methods similar to those adopted for costing the Operational Support Program (code 500).

Table 13 summarizes the procedures which we have adopted provisionally for costing the non-system research and development activities listed in Table 12. It should be emphasized that work in this area is continuing, that the results are tentative, and that the cost figures obtained by these methods (intended only for total force cost analysis) are not appropriate for programming or budgetary use.

In addition to the categories in Table 13, we include several miscellaneous items in estimating non-system innovation costs, e.g., (1) non-system installation requirements (300-money), and (2) pay and allowances (500-money) of military personnel on duty throughout ARDC.

ELECTRONIC DATA PROCESSING

Electronic processing of force structure data has made it possible to reduce the calculating time from weeks to hours, and to improve the cost model in ways which would not have been practicable with the use of

Table 13

COSTING PROCEDURES FOR NON-SYSTEM RESEARCH AND DEVELOPMENT ACTIVITIES

<u>Operational Support</u>

Definition:	Operational Support consists of individual items of equipment, skills, or techniques for which there is a HqUSAF-stated requirement; the items are not identifiable as components of weapon, control, or support systems, but support Air Force tasks.
Examples:	At present under development are "Hypersonic Altitude and Airspeed Instrumentation," "Pressure Suits and Accessories," "J57 F 43MA Engine Modification," "Petrol Servicing and Handling Equipment."
Suggested Estimating Procedure:	Up to the present we have extrapolated the dollar requirements of these activities as a single aggregate mean of the amount funded by the Air Force in this area over the last three years, increasing at a moderate rate per year. It is also highly desirable to make individual line item projection for expected high cost projects.

<u>Advanced Systems</u>

Definition:	Advanced systems are composed of equipment, skills, and techniques the composite of which is useful as a vehicle for advancing technology. Design, development, and construction of advanced systems are directed toward extending the frontiers of scientific knowledge and solving technical problems which are designed to facilitate the early attainment of an operational capability.
Examples:	Examples of "Advanced Systems" currently under development include "X-15," "X-18," VTOL, "Hiller Tilt Wing," "DYNA SOAR," "Nuclear Powered Strategic Bomber System."
Suggested Estimating Procedure:	System by system projection with the addition of new projects at a rate sufficient to keep the total funds in this category increasing at a moderate rate per year over the level of fiscal year 1960.

<u>Test Instrumentation</u>

Definition:	Special equipment or techniques required to perform research and development tests. (Includes both instrumentation, development and procurement.)
Examples:	"AFMDC Range Instrumentation," "Multi-Orthicon Camera Fence," "Rocket Engines for Sleds," "Balloon Components."
Suggested Estimating Procedure:	Same as "Advanced Systems."

<u>Development Support</u>

Definition:	That part of advanced development involving the programming of resources for contractual organizations that provide specialized technical and scientific efforts not normally available within the Air Force.
Examples:	RAND, Lincoln Laboratories, Anser.
Suggested Estimating Procedure:	Project mean amount funded over the last three years.

Table 13--Continued

<u>Applied Research</u>

Definition:	Exploration of knowledge, materiel, and techniques to demonstrate experimentally a solution to an anticipated operational need.
Examples:	"Solid Rocket Aging," "Oxidizers, High Energy Storables," "Power Transmission Techniques," "Solar Energy Conversion Research," "Crystal Physics."
Suggested Estimating Procedure:	Up to the present, we have extrapolated the dollar requirements of these activities as a single aggregate mean of the amounts funded by the Air Force in this area over the last three years, increasing at a moderate rate per year.

<u>Basic Research</u>

Definition:	Research directed toward an increasing in fundamental knowledge in science. It includes theoretical analyses, exploration, and experimentation aimed at a fuller knowledge and/or understanding of the subject under study.
Examples:	"Research on Nuclear Phenomena," "Research in Electromagnetic Energy Transfer," "Research on Cosmic Radiation," "Research on Behavioral Sciences."
Suggested Estimating Procedure:	Same as Applied Research.

<u>Command Operations</u>

Definition:	Command Operations consist of two separate operations, both of which encompass resources such as manpower, materiel, and facilities. (a) General Technical Operations include operation, maintenance and management of Air Force research development and test facilities. (b) Housekeeping and Base Support includes operation and management of functions related to air base wing or group mission.
Examples:	"Rome Air Development Center Operation and Maintenance," "Hq. ARDC Det. 1 Operation and Maintenance," "Operation of AFMTC Down Range Tracking Network by Pan American," "Data Collection Equipment Station - AFMTC New Facility."
Suggested Estimating Procedure:	In the past, we have divided the ARDC centers into two groups: (1) those which were essentially weapon test centers, and (2) those more concerned with non-system research and development activities. The former were estimated as a function of weapon [illegible] and the latter of non-weapon system funds for a given fiscal year. In recent years, we have included an increment in weapon system test operations to include the free support given NASA and ARPA.

manual computing methods. In RAND the program is written for the large memory IBM 7090 computer, and is designed for flexibility to allow for continuing improvements in methodology. It should be emphasized that EDP is not a substitute for skill in analysis or for insight in identifying areas of cost sensitivity. It is a method which provides for great rapidity in routine calculating and bookkeeping activities, but it is little more. The subjective judgment of the trained analyst continues to be essential to successful cost analysis. The following description of processing methods is therefore offered more as an example than as a guide.

Types of Data

Processing begins with the preparation of keypunch input sheets. For computational purposes, it is convenient to treat the data in four groups, depending on whether the data apply to the Air Force as a whole or to a single system, and on whether they are constant or variable from year to year.

Type 1--Air Force Constant Data. These data represent a simplification introduced into the cost model. Although in reality they differ somewhat from system to system, the use of over-all figures gives a result within reasonable limits of accuracy. An example of the keypunch sheet is given in Fig. 7, which lists the various inputs.

Type 2--Air Force Yearly Data. These data are of several kinds, illustrated by the keypunch sheets given in Figs. 8a and 8b. Figure 8b shows personnel ceilings and support aircraft dollar costs, in parallel columns for successive fiscal years. Figure 8a shows keypunch sheets for the conversion factors which relate "deliveries" (i.e., activity dates) to expenditures and program requirements.

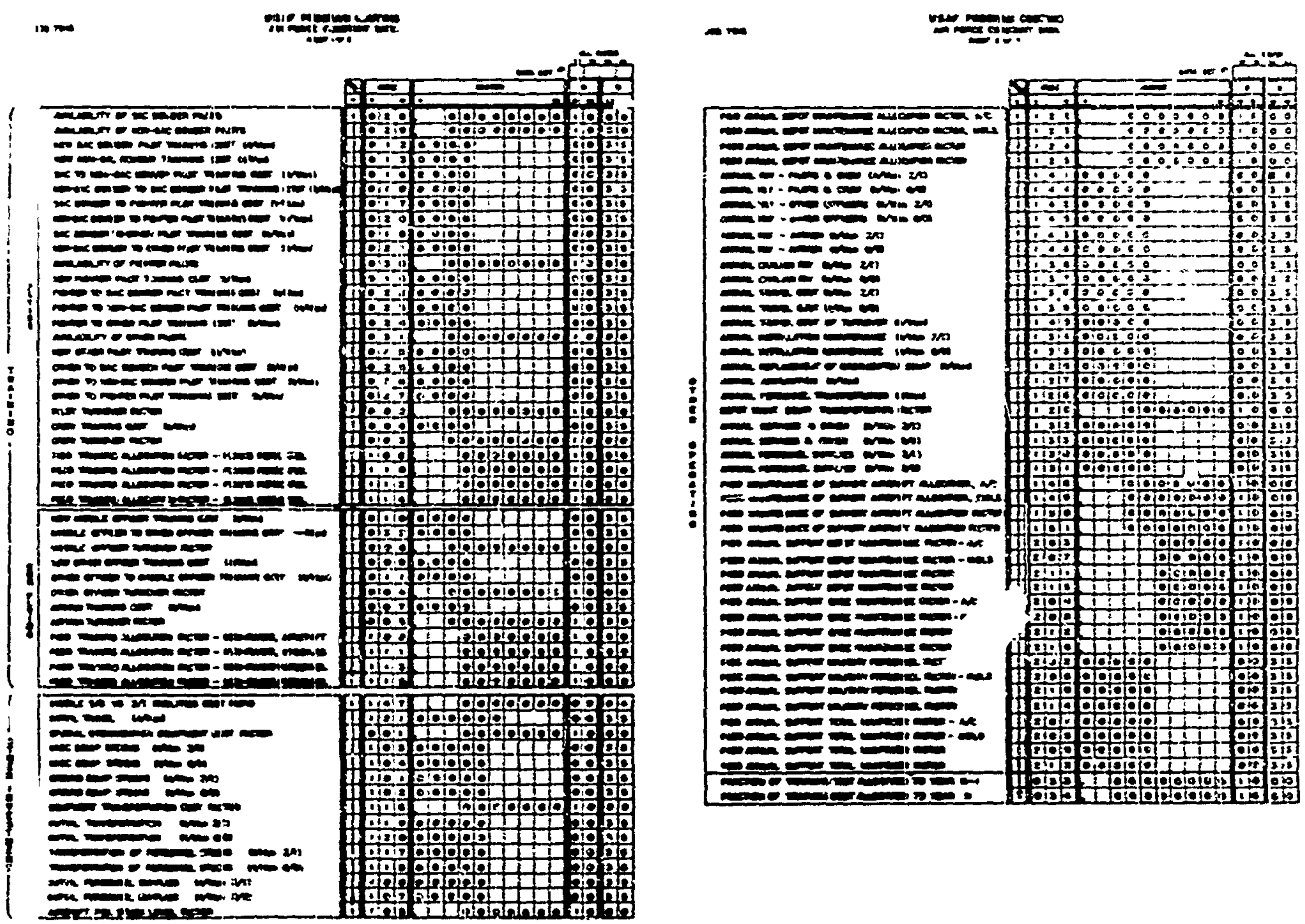
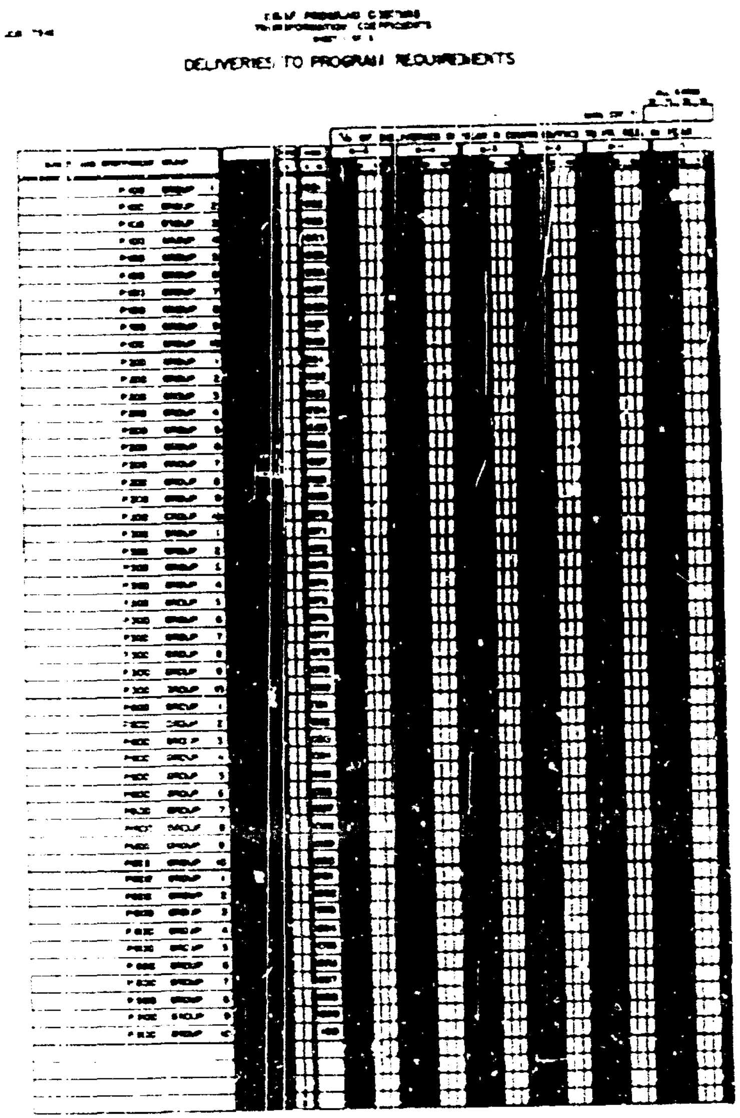


Fig. 7—EDP inputs, type I (Air Force constant data)



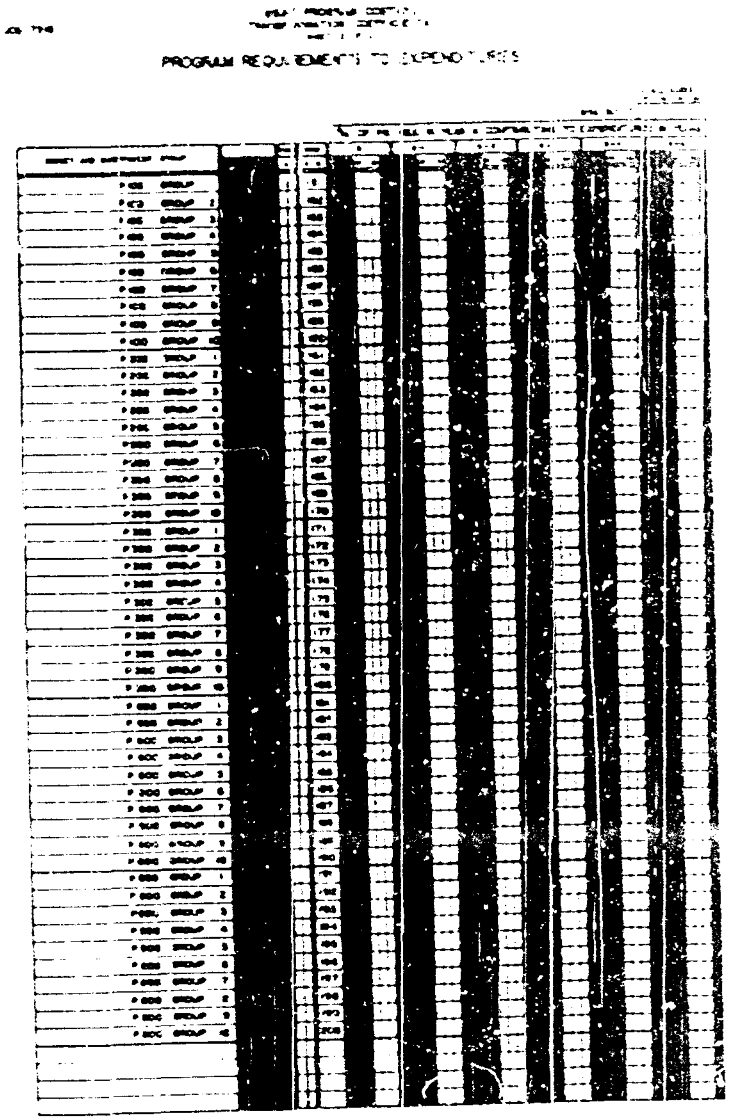


Fig. 8a—EDP inputs, type 2 (Air Force yearly data)

.08 7548

USAF PROGRAM COSTING
AIR FORCE YEARLY DATA

DATA SET ID — ALL CARDS 77 78 79 80

N = FISCAL YEAR ______

		TYPE	CARD	N-1	N	N+1	N+2	N+3	N+4
STRATEGIC	OFFICER CEILING	2	01						
	AIRMEN CEILING		06						
	CIVILIAN CEILING		11						
	MAINT OF SUPPORT A/C (8)		20						
	MODIF OF SUPPORT A/C (8)		28						
	POL FOR SUPPORT A/C (8)	2	24						
DEFENSE	OFFICER CEILING	2	03						
	AIRMEN CEILING		08						
	CIVILIAN CEILING		13						
	MAINT OF SUPPORT A/C (8)		22						
	MODIF. OF SUPPORT A/C (8)		30						
	POL FOR SUPPORT A/C (8)	2	26						
TACTICAL	OFFICER CEILING	2	02						
	AIRMEN CEILING		07						
	CIVILIAN CEILING		12						
	MAINT OF SUPPORT A/C (8)		21						
	MODIF. OF SUPPORT A/C (8)		29						
	POL FOR SUPPORT A/C (8)	2	25						
MATS	OFFICER CEILING	2	04						
	AIRMEN CEILING		09						
	CIVILIAN CEILING		14						
	MAINT OF SUPPORT A/C (8)		23						
	MODIF OF SUPPORT A/C (8)		31						
	POL FOR SUPPORT A/C (8)	2	27						

Fig 8b—EDP inputs, type 2 (Air Force yearly data)

Type 3--Weapon and Support System Constant Data. These data are assembled as shown in Fig. 9.

Some inputs are appropriate to all systems; others relate specifically to individual aircraft, missile or surveillance systems. The three types of systems are treated differently in computing training and various miscellaneous costs; and for personnel training a further distribution is made by type of aircraft.

Type 4--System Yearly Data. By far the largest component of EDP inputs consists of system yearly data. This will be understood if it is remembered that the total force includes numerous individual systems, that systems are being more or less rapidly phased in or out, and that they are analyzed on a per-squadron basis (per-site, in the case of radar). For Type 4 data many specialized kinds of keypunch input data sheets are therefore required--usually 20 or more kinds in each total force cost analysis. Table 14 lists the kinds of system yearly data sheets employed in a typical analysis, and Fig. 10 reproduces two of the sheets.

For every complete analysis of total force costs there is a set of constant and yearly data for the Air Force as a whole, and a set of constant and yearly data for each of the many weapon and support systems. Complete analysis requires, therefore, a very substantial amount of data preparation, if carried out from the beginning. Once prepared, however, much of the data can be used in subsequent analyses, particularly in the study of alternative structures which are variations of the same basic pattern. After the initial analysis, such alternatives can be costed very rapidly by EDP techniques.

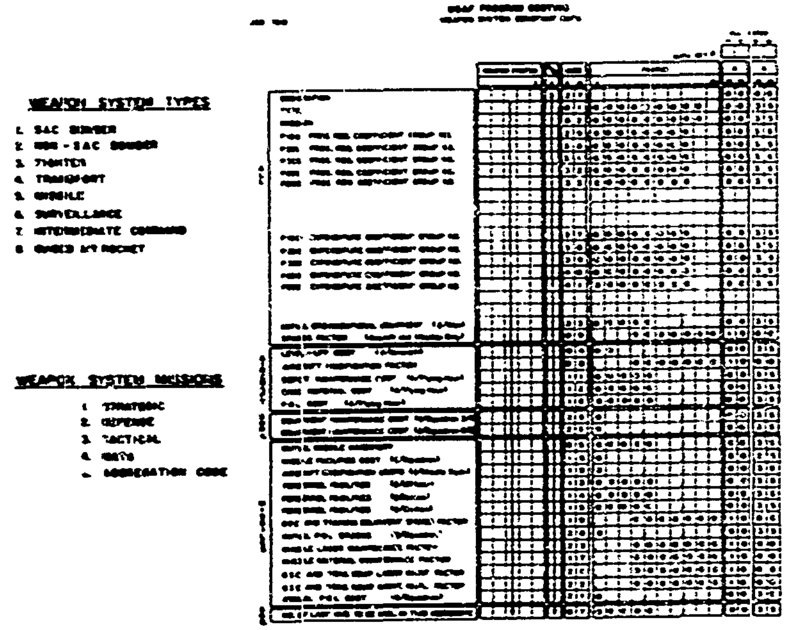
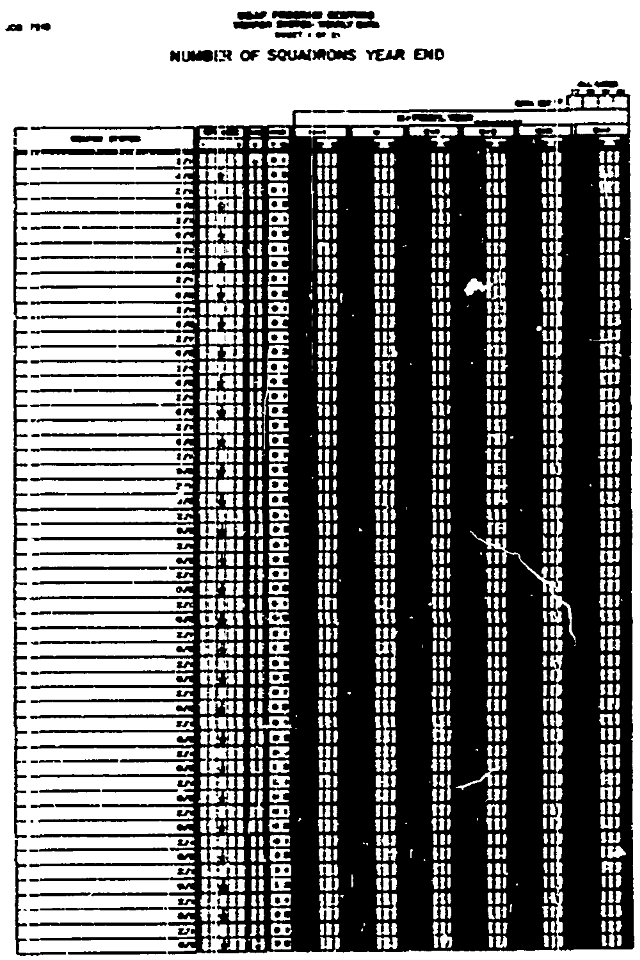


Fig. 9—EDP inputs, type 3 (system constant data)



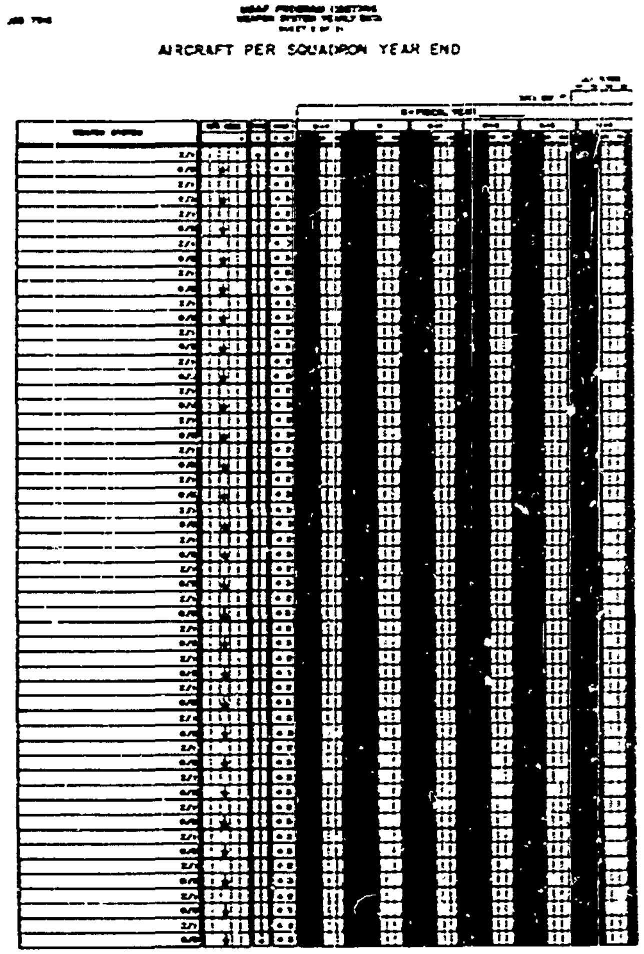


Fig. 10—EDP inputs, type 4 (system yearly data)

Table 14

EDP INPUTS: LIST OF TYPE 4 DATA SHEETS

(System Yearly Data)

1. Number of Squadrons Year End
2. Aircraft per Squadron Year End
3. Annual Flying Hours per Aircraft
3A. Total Annual Flying Hours per Weapon System
4. Missile Squadrons for which Facilities Are Not Costed
5. Pilots per Squadron
6. Other Crew Officers per Squadron
7. Missile Officers per Squadron
8. Total Officers per Squadron
9. Airmen per Squadron
10. Civilians per Squadron
11. Research and Development Costs
12. Initial Installations Cost, P-300 Money
13. Procurement of Major Equipment, P-100 Money
14. Average Cost per Missile (millions of dollars)
14A. Average Cost per Missile (thousands of Dollars)
15. Missile Procurement Data
16. Major Equipment Costs, P-800 Money, Surveillance
17. Missile Ground-Support, Training, and Airborne Equipment Cost per Squadron
18. SAGE Special Services P-400 Money
19. Initial Support Cost, P-100 Aircraft, Guided Aircraft Rockets, P-200 Missiles, P-800 Surveillance
20. Initial Support Cost, P-200 Money
21. Modification and Attrition of Support Major Command Aircraft P-100 Money.

Phases of Calculation

The operation of the computer program may be visualized as shown in Fig. 11. A complete "pass" is made at the data in each phase. In Phase I the raw data are put in and from them are computed the gross requirements for personnel and the factors needed to adjust personnel requirements to personnel ceilings. Phase II calculates adjusted personnel requirements, missile and aircraft inventories, training requirements (number of personnel), and elements to be used in allocating training and other costs. Phase III allocates training and other costs and computes totals on the basis of delivery dates. The final or "totals" phase converts time-of-delivery costs into fiscal year expenditures and program requirements. Results are then summarized and printed out.

Printouts

The format of a printout is determined by the following factors:

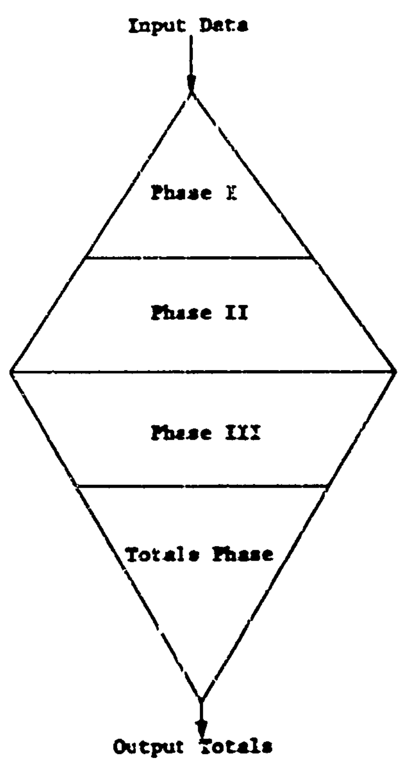
(1) Period of years covered

(2) Type of money

(3) System detail

(4) Cost element detail

At RAND totals are often given for each of ten successive fiscal years. Program requirements which lead into the year preceding the first year and expenditures which lag beyond the final year are not printed out. Type of money refers to costs identified as program requirements or expenditures and broken down by budget series appropriation code. System detail refers to the degree of aggregation of results. Totals may be given for the Air Force as a whole, or for individual systems, groups of systems, or missions. Cost element detail refers to innovation, investment,



Computes:
  Gross personnel requirements
  Factors to adjust requirements to ceilings

Computes:
  Personnel requirements adjusted to ceilings
  Aircraft and missile inventories
  Training Requirements
  Bases for allocation of miscellaneous costs

Allocates training and miscellaneous costs
Summarizes total costs on a "delivery schedule" basis

Converts "delivery" costs to program requirements
  and to expenditures
Summarizes data into final output totals

Fig. 11 -- EDP Operation Phases

and operation costs. Totals may be given for those three major cost categories, as well as for their principal elements.

Table 15 shows four typical output formats. Format One is the most detailed and in practice it is seldom necessary to seek greater detail than it provides. However, electronic data processing makes it possible to obtain additional detail in a very short time (within the limits of the cost model), as well as to obtain special types of totals, e.g., the costs of major commands.

Table 15

MIP OUTPUTS. EXAMPLES OF FORMATS

Format One

Year		n	n+1	n+2	n+3	n+4	n+5	n+6	n+7	n+8	n+9
Force Structure - Squadrons		$									
Manning: Pilots		$									
Crew Officers		$									
Missile Officers		$									
Other Officers		$									
Total Officers		$									
Airmen		$									
Total Military		$									
Civilians		$									
Research and Development Costs	P-100	$									
	P-200	$									
	P-300	$									
	P-400	$									
	P-500	$									
	P-600	$									
	Total	$									
Investment Costs: Installations	P-300	$									
Major Equipment	P-100	$									
	P-200	$									
	Total	$									
Initial Stocks	P-100	$									
	P-200	$									
	P-400	$									
	P-500	$									
	Total	$									
Initial Supply	P-100	$									
	P-200	$									
	P-400	$									
	P-500	$									
	Total	$									
Miscellaneous Investment	P-100	$									
	P-200	$									
	P-400	$									
	P-500	$									
	Total	$									
Total Investment Costs	P-100	$									
	P-200	$									
	P-300	$									
	P-400	$									
	P-500	$									
	Total	$									
Operation Costs:											
Major Equipment and Miscellaneous Operation	P-100	$									
	P-200	$									
	P-300	$									
	P-400	$									
	P-500	$									
	Total	$									
Personnel Operation	P-100	$									
	P-200	$									
	P-400	$									
	P-500	$									
	Total	$									
Support	P-100	$									
	P-200	$									
	P-400	$									
	P-500	$									
	Total	$									

Table 15--continued

		Year	n	n+1	n+2	n+3	n+4	n+5	n+6	n+7	n+8	n+9
Total Operation Costs	P-100		$									
	P-200		$									
	P-300		$									
	P-400		$									
	P-500		$									
	Total		$									
Summary	P-100		$									
	P-200		$									
	P-300		$									
	P-400		$									
	P-500		$									
	P-600		$									
	Grand Total		$									
Format Two												
Force Structure - Squadrons			$									
Manning: Military			$									
Civilians			$									
Research and Development			$									
Investment			$									
Operation			$									
	Grand Total		$									
Format Three												
Force Structure - Squadrons			$									
Manning: Military			$									
Civilians			$									
	P-100		$									
	P-200		$									
	P-300		$									
	P-400		$									
	P-500		$									
	P-600		$									
	Grand Total		$									
Format Four												
Force Structure - Squadrons			$									
Manning: Military			$									
Civilians			$									
Innovation	P-100		$									
	P-200		$									
	P-300		$									
	P-400		$									
	P-500		$									
	P-600		$									
	Total		$									
Investment	P-100		$									
	P-200		$									
	P-300		$									
	P-400		$									
	P-500		$									
	Total		$									
Operation	P-100		$									
	P-200		$									
	P-300		$									
	P-400		$									
	P-500		$									
	Total		$									
Summary	P-100		$									
	P-200		$									
	P-300		$									
	P-400		$									
	P-500		$									
	P-600		$									
	Grand Total		$									

SUMMARY

Total force cost analysis is a method developed for estimating the annual cost implications of proposed force structures. It is applicable to a wide range of studies: of individual weapon systems, of major missions, and of whole military services. In each case the study is placed in the context of a total force--in practice, of the total Air Force. The period of the study is extended in time so as to take into account the time lags from program requirements to expenditures and activity dates. The method attempts to take into account the various resource relationships among weapon and support systems. Vast quantities of data are required, and electronic computers are employed to speed calculations and provide timely results. Presentation of results is complicated and itself requires special techniques.

The course of analysis is summarized schematically in Fig. 12. Analysis begins with the specification of the force composition and major operational assumptions. More detailed specification of assumptions continues while the basic data are developed and entered on keypunch sheets. Computer calculations are then carried through various phases, and the results are reviewed and prepared for presentation.

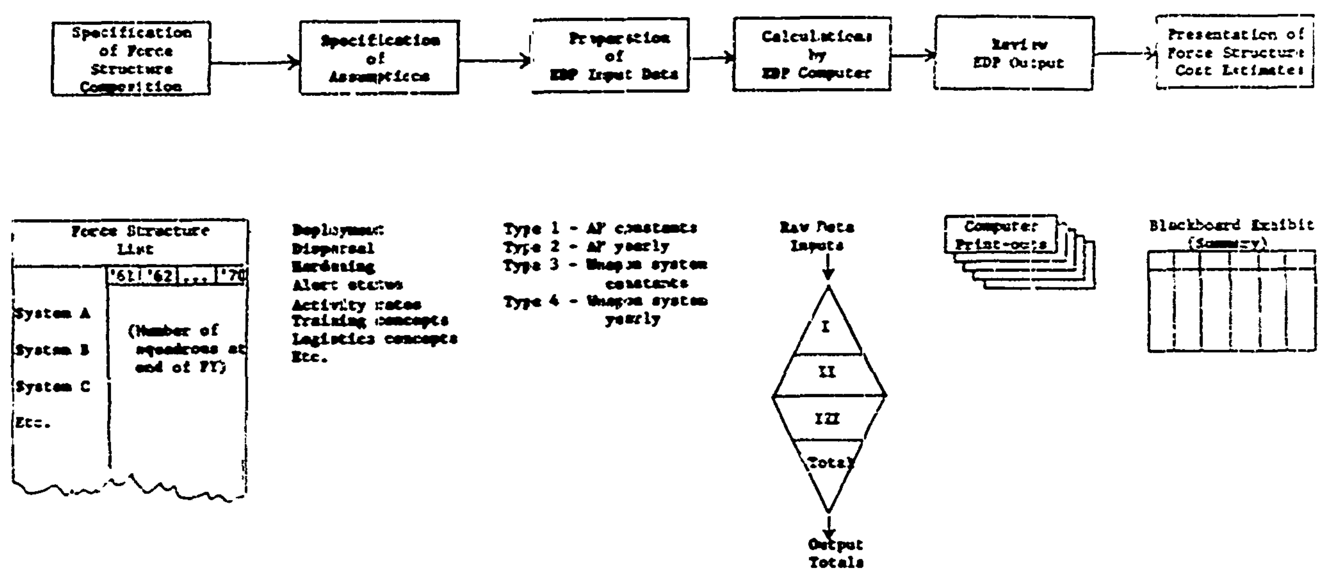


Fig.12—Major steps in total force cost analysis

CHAPTER IV

COST SENSITIVITY ANALYSIS

Cost sensitivity analysis attempts to answer the following questions: How does the cost of a system vary as a result of changes in the configuration of the system? To what elements (considering operational assumptions as well as hardware specifications) is the total cost of the system especially sensitive or insensitive? Similar questions may be asked with respect to total force structures.

In a recent study carried out at RAND, a proposed system was costed for 36 different configurations, in which the following elements were varied within certain ranges: force size, warhead weight, type of propulsion, squadron size, fixed or mobile operation, degree of dispersal, activity rate, and logistics support concept. Even with force size held constant, the other variations in configuration produced a range of system costs varying from a minimum of $10 billion to a maximum of $21 billion. Repetitive costing, with some elements of the configuration held constant and others varied singly or in groups, soon revealed the elements to which costs were sensitive or insensitive.

Except for this repetition or iteration, cost sensitivity analysis is basically no different in method from cost analysis as already described. It benefits, of course, from techniques which facilitate repetition, such as the generalized cost-estimating relationships discussed under investment costs. And it is facilitated by electronic data processing. As in other analyses, consistency is important in cost sensitivity analysis, and the analyst should be careful to avoid any methodological bias in favor of a particular system.

EXAMPLES OF COST SENSITIVITY ANALYSIS

Perhaps the best way to describe cost sensitivity analysis would be to give some examples of its use, both in individual system and total force cost analysis. So that security restrictions will not inhibit our choice of examples, the systems are not always identified and the charts are presented without numerical values. Nonetheless, we believe that they will effectively illustrate some of the basic principles of cost sensitivity analysis.

Figure 13 shows sensitivities and insensitivities revealed by costing various configurations of a ballistic missile system.

(1) The system cost is relatively insensitive to increases in payload; that is, a considerable increase in payload can be obtained for relatively small increases in cost. The explanation is that a number of the expensive components of the system change little with increases in gross weight of the missile (e.g., guidance and control systems, ground support equipment, and installations items associated with fire control and flight vehicle guidance).

(2) The system cost is relatively sensitive to type of propellant used. The explanation is that the use of solid or storable liquid propellants eliminates the need for the expensive storage and transfer facilities and equipment required by cryogenic propellants.

(3) The system cost is relatively sensitive to the automation of the ground environment. The explanation in this case is that an automated environment requires less launch-site checkout equipment and personnel and personnel facilities.

Figure 14 illustrates a missile system's cost sensitivity to the

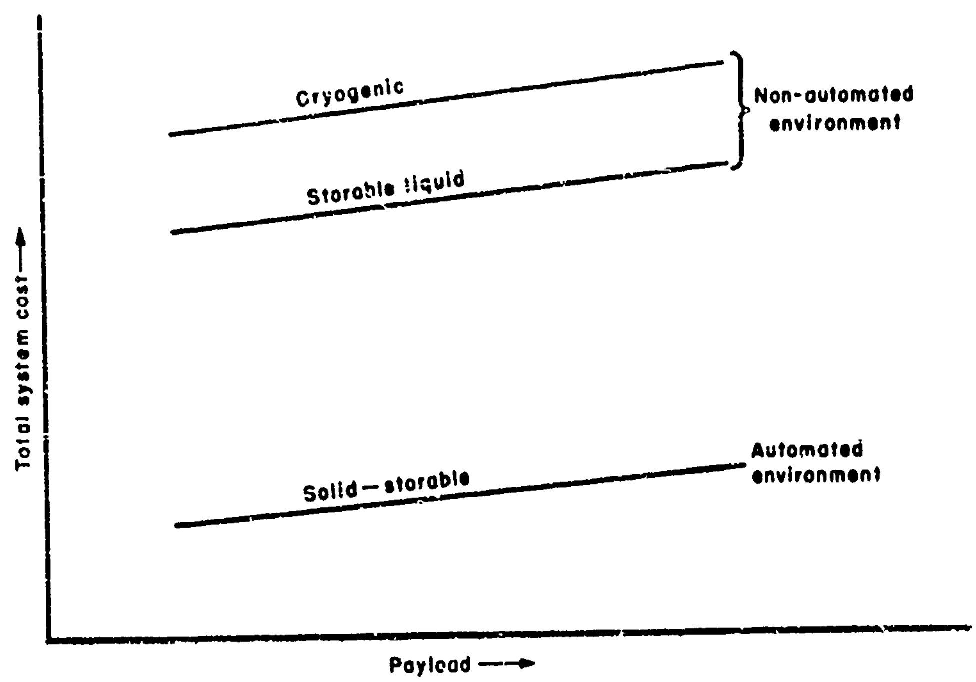


Fig. 13 — Missile system cost vs payload for various types of propellants and ground environments

(Fixed number of ready missiles)

reliability of its components, as measured by the probability of a successful launch and by the average length of time a weapon could remain on alert status without maintenance (i.e., "mean time to failure"). Very significant reductions in system cost would result from improvements in these characteristics; and the potential savings might justify additional innovation costs aimed at improved component reliability.

Figure 15 illustrates a boost-glide system which is initially quite sensitive to increases in the weight of the warhead. The cost curve shows that the sensitivity decreases with increasing warhead weight, so that after a point we could buy substantial increases in weight for only moderate rises in system cost. Figure 16 displays (on a slightly different scale) the major elements of cost which contribute to the total cost curve shown in Fig. 15. From this breakdown it is apparent that the cost of the operational flight vehicles is the most important element in the total cost curve, although other elements also contribute to its change of slope.

Figure 17 illustrates a case in which the total cost of a system initially decreases and then increases as one of the system characteristics is altered toward higher values. The system includes a number of satellites in orbit, and as their altitude is increased, the cost of the system falls markedly at first, primarily because the change in altitude makes it possible for fewer satellites to do the job. But after a point this saving is counterbalanced by the increasing costs of other components: the larger boosters, more sensitive instrumentation, and more powerful communication equipment needed for the greater altitudes. The point is that the cost implications of the system are fully revealed only by

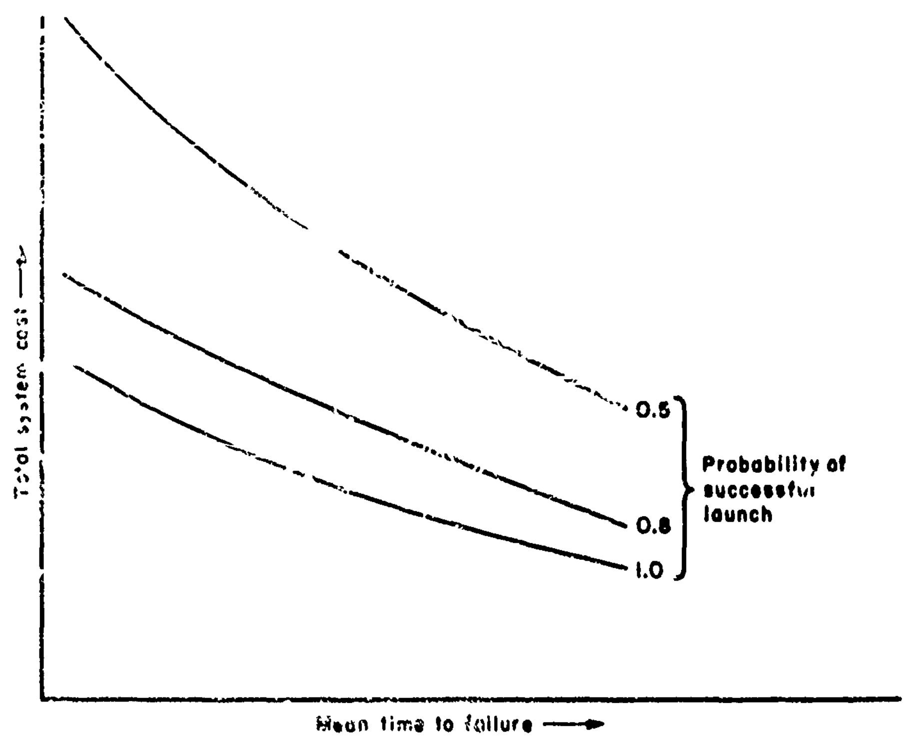


Fig. 14—Missile system cost vs mean time to failure for various probabilities of successful launch

(Fixed number of launched missiles)

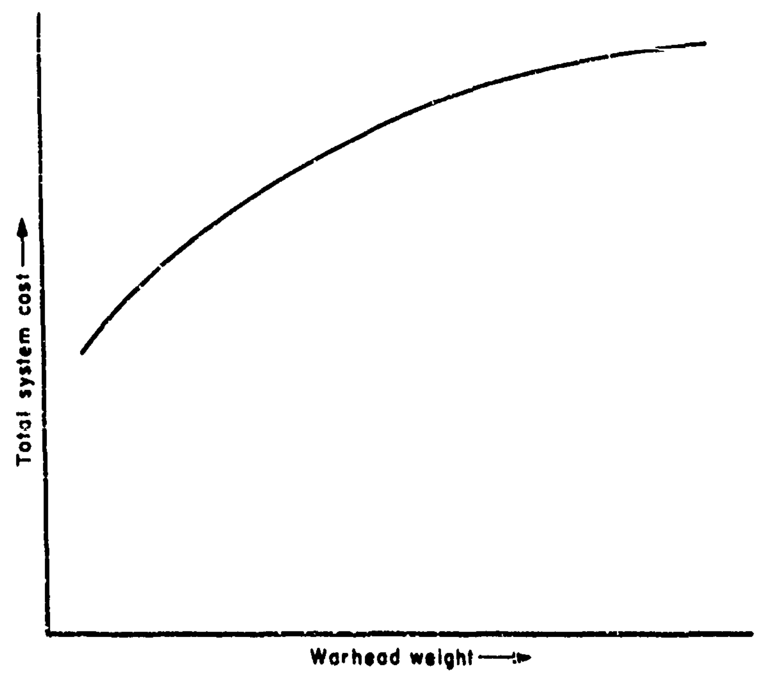


Fig.15 — Boost-glide system cost vs warhead weight
(Fixed ready vehicle force)

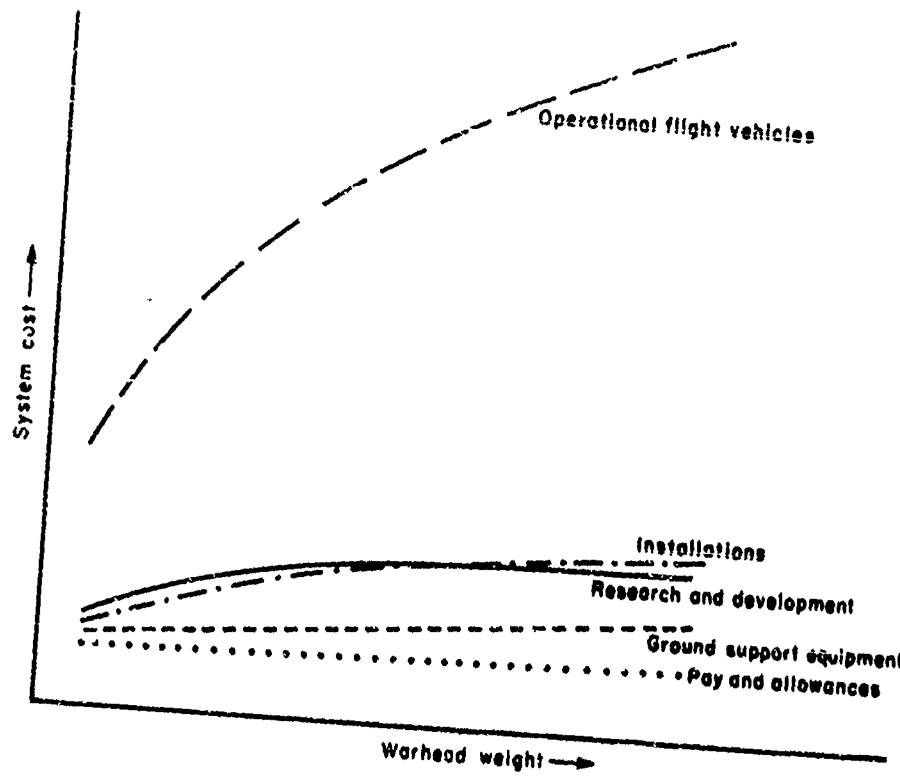


Fig. 16—Major elements of cost in Fig. 15
(Shown on a slightly different scale)

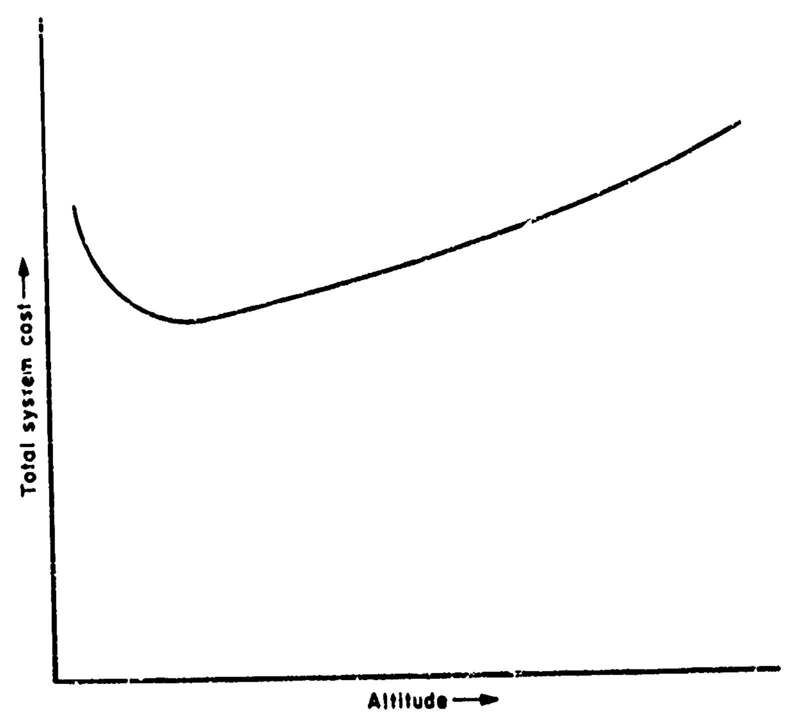


Fig. 17 — Satellite system cost vs altitude
(Fixed job to be done)

costing a wide range of system configurations. Not only can the slope of the cost curve suggest possibilities of advantageous trade-offs between cost and system characteristics; in some cases, points of minimum cost can be located apart from points of minimum performance.

Table 16 illustrates cost sensitivity analysis applied, not to a single system, but to the group of systems making up the strategic mission. In a recent RAND study, seven variations of a basic strategic mission were investigated as part of a total force cost analysis. Force structure changes were proposed as shown in the "Number of Squadrons" panel and the cost implications were shown in the "Total Expenditures" panel. (For security reasons, only a few numerical results are given here.)

USES AND ADVANTAGES OF COST SENSITIVITY ANALYSIS

The systems analyst may be only touching the surface of the cost-effectiveness problem unless he studies, not only alternative system proposals, but also alternative configurations for each of the systems under analysis. For this purpose he requires the results of a cost sensitivity analysis giving a range of estimates corresponding to various system specifications and assumptions. This is as true for the more subjective long range military planning and programming as it is for the formal systems analysis with effectiveness specified and alternative systems described in concrete detail.

In total force structure studies, the cost of a given structure is of vital interest, but it is likely to be only a starting point for further investigations as the original structure is adjusted to bring it within given budgetary limits while maintaining an acceptable level of effectiveness. In this iterative process of structure adjustment, total force cost

Table 16

FORCE STRUCTURE COST SENSITIVITY ANALYSIS FOR THE STRATEGIC MISSION
(Base case and seven alternative plans)

Weapon System	Base Case				Case 1				Case 2				Case 3				Case 4				Case 5				Case 6				Case 7			
	FY1	2	3	4	FY1	2	3	4	FY1	2	3	4	FY1	2	3	4	FY1	2	3	4	FY1	2	3	4	FY1	2	3	4	FY1	2	3	4
	Number of Squadrons at End of Fiscal Year																															
B-52	x	x	x	x					On air alert																							
B-47	x	x	x	x																	Procurement cuts					Rapid phase out						
B-58	x	x	x	x																												
B-X	x	x	x	x																												
BM-65	x	x	x	x	Increased				Increased				Increased				Increased				Increased				Moderate increase				Moderate increase			
BM-68	x	x	x	x																												
Missile X	x	x	x	x									Earlier phase-in				Later phase-in															
Missile Y	x	x	x	x																												
Etc.																																
	Total Expenditures, Strategic Mission (Billions of Dollars)																															
B-52																																
B-47																																
Etc.																																
Total*					-	0.3	1.0	0.1	0.1	0.7	1.5	0.4	-	0.5	1.4	0.7	-	0.3	1.2	0.1	(0.5)	(1.1)	(0.4)	(1.5)	(0.9)	(1.7)	(0.9)	(0.5)	0.3	0.8	1.3	(0.1)

*Differences from base case. ( ) denotes negative quantity.

sensitivity analysis gives valuable insights into the choices available.

Cost sensitivity analysis is a useful technique for dealing with problems of uncertainty, the more so because statistical methods for deriving confidence limits and other criteria of uncertainty cannot be applied generally to cost estimates. In studying proposed future systems, numerous uncertainties must be recognized together with their impact on system costs. For example, there are uncertainties about the size of the system force, the future price levels, and the configuration of the system (hardware specifications and operational assumptions). Studies of systems historical data have shown that perhaps the most important reason for differences between early estimates and final costs is that the configuration of the system ultimately obtained differs considerably from that envisaged early in the program. Cost sensitivity analysis deals explicitly with cost differences related to differences in system configuration, and it can therefore provide a range of system costs which is likely to be a more realistic guide than a single, most probable cost.

CHAPTER V

PRESENTATION OF RESULTS

It is not enough that the analyst should produce timely and reliable cost estimates. The data are so numerous, the results so complex, and their various applications still so little understood generally, that the analyst's work is only half done unless he presents his conclusions in such a way that they can be readily understood and quickly made use of. Presentation of results cannot be reduced to a few rules to be followed mechanically. Presentation is a form of interpretation which requires the professional skill and attention of the cost analyst. He must understand and keep in mind the needs of system analysts and Air Force planners and programmers. And these needs will not only influence the method of presentation, but also, to some degree, they will influence the analyst's choice of cost model and costing techniques.

In discussing cost sensitivity analysis we have already illustrated some graphical methods for presenting estimates characterized by a range of a series of values arising from uncertainties about system performance (e.g., Fig. 14) or developed by varying the configuration of a system (e.g., Figs. 13, 15, 17). Table 16 displays a tabular method of comparing alternative mission structures built around the same basic elements. This type of table can be adapted for many uses, and is employed at RAND for total force studies as well as studies of mission structures.

In the present chapter we will describe briefly or refer to a number of other formats and methods of presentation which have been found useful.

A summary of costs like that shown in Table 17 is often useful in itself and also serves as a convenient method of recording results for

Table 17

PRESENTATION OF SYSTEM COSTS BY COST CATEGORIES

(Format for a Missile System)

	Estimated Cost
I. RESEARCH AND DEVELOPMENT COSTS	
System Development	
Preliminary study and design	xx
Design engineering	xx
Hardware fabrication	xx
System Test and Evaluation	
Vehicle fabrication	xx
Captive test operations	xx
Flight test operations	xx
Test equipment	xx
Installations	xx
Other System Research and Development Costs	
Depot maintenance and supply	xx
Minor modifications	xx
Miscellaneous	xx
TOTAL RESEARCH AND DEVELOPMENT COST	$xxx
II. INVESTMENT COSTS	
Installations	xx
Equipment	
Primary mission	xx
Specialized	xx
Other	xx
Stocks	
Initial stock levels	xx
Equipment spares and spare parts	xx
Initial training	
Formal training	xx
Missiles consumed in initial training	xx
Miscellaneous	xx
TOTAL INVESTMENT COST	$xxx

	3 Years	5 Years	7 Years
III. OPERATION COSTS			
Equipment and Installations Replacement			
Primary mission equipment	$ xx	$ xx	$ xx
Specialized equipment	xx	xx	xx
Other equipment	xx	xx	xx
Installations	xx	xx	xx
Maintenance			
Primary mission equipment	xx	xx	xx
Specialized equipment	xx	xx	xx
Installations	xx	xx	xx
Pay and allowances	xx	xx	xx
Training	xx	xx	xx
Fuels, lubricants and propellants	xx	xx	xx
Services and miscellaneous	xx	xx	xx
TOTAL ANNUAL OPERATION COST	$xxx	$xxx	$xxx

IV. TOTAL SYSTEM COSTS

Research and Development + Investment + Operation for 3 years	$xxxx
Research and Development + Investment + Operation for 5 years	$xxxx
Research and Development + Investment + Operation for 7 years	$xxxx

incorporation in later studies.

If the costs of research and development, investment, and operation differ significantly between alternative systems, it is important to present estimates for several periods of operation, say 3, 5, and 7 years. The cheaper system in the short run may be the more expensive in the long run if it has greater operation costs. The choice between systems may therefore turn on the projected period of operation. If the time-phasing of cost estimates is of particular interest, presentations based on Figs. 2a and 2b may be used.

For many purposes presentation of results in terms of the Air Force budget code series is desirable, and adaptations of computer output forms can be used such as Format Four of Table 15. The numerical results can be given as either program requirements or expenditures.

Table 18 illustrates a typical format used in presentation of the summary results of a total force cost exercise. Sometimes the summary is presented in a more detailed form: for example, investment costs may be broken down into installations, major equipment, initial stocks, initial training, etc.; and operation costs may be shown in terms of maintenance, pay and allowances, replacement training, fuels, lubricants and propellants, etc.

Presentation of total force cost estimates is a particularly difficult task because of the large volume of data involved. For initial presentation, RAND relies at present on a combination of blackboards for summary data and computer printouts for detailed data. The aim is to present results in a meaningful manner as soon as possible. Later when the cost implications have been thoroughly considered, and if necessary, force

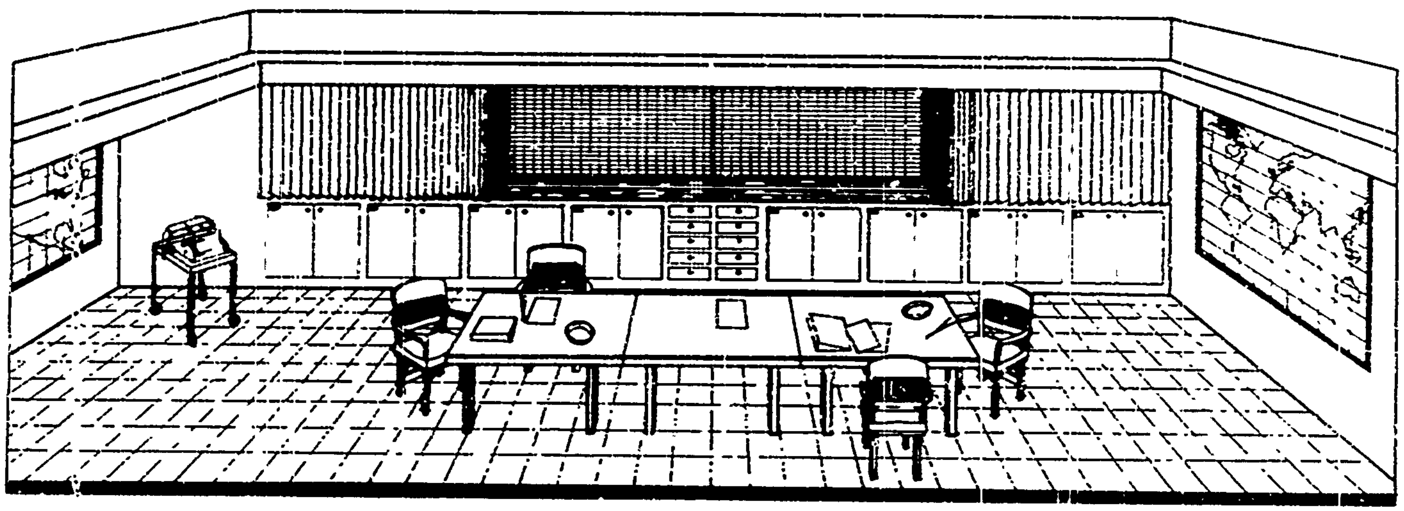
Table 18

FORMAT FOR PRESENTING SUMMARY OF TOTAL FORCE STRUCTURE COST ESTIMATES

Force Structure: Programs and Systems	Force Structure: Number of Squadrons (end of fiscal year)	Manpower Requirements (thousands of people): Military	Manpower Requirements (thousands of people): Civilian	Expenditures (or "Program Requirements") (millions of dollars): Research and Development	Expenditures: Investment	Expenditures: Operating	Expenditures: Total Expenditure
STRATEGIC							
[illegible]							
[illegible] (incl. [illegible])							
[illegible]							
[illegible]							
[illegible]							
[illegible]							
[illegible]							
[illegible]							
[illegible]							
[illegible]							
Other Strategic							
Total Strategic							
DEFENSE							
[illegible] (incl. [illegible])							
[illegible] (incl. [illegible])							
[illegible]							
[illegible]							
[illegible] ([illegible])							
[illegible]							
[illegible]							
[illegible]							
Other Defense							
Total Defense							
TACTICAL							
[illegible]							
[illegible]							
[illegible]							
[illegible]							
Troop Carrier							
[illegible]							
Other Tactical							
Total Tactical							
MISCELLANEOUS							
[illegible]							
Other Miscellaneous							
Total Miscellaneous							
GRAND TOTAL							

structures adjusted and system proposals revised, cost estimates are placed in more permanent form in typed reports with charts prepared by the graphic arts department.

RAND makes use of a specially designed room for the development, presentation and discussion of total force costs. Figure 18 shows a sketch of that room. Basic tabular data are posted on sliding blackboards using a format similar to that shown in Table 18. Multiple sets of blackboards are arranged so as to facilitate rapid posting, flexibility, and comparison of results. Storage area for computer runs is provided in the drawers and cabinets below the blackboard area. A permanent blackboard and chart rack, along with chart storage area, is contained in the back wall shown in the lower half of Fig. 18. Our experience indicates that a facility of this kind is of great assistance in total force cost analysis and in the successful presentation of its results.



Main working area, showing sliding blackboards

Back wall for display and storage

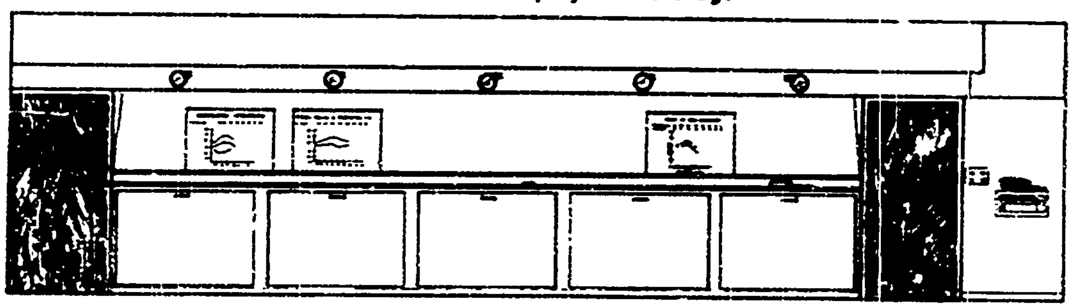


Fig.18—Room for display and discussion of total force cost analysis

Fig.18—Room for display and discussion of total force cost analysis

Fig.18—Room for display and discussion of total force cost analysis

Appendix

ANALYSIS OF MANPOWER REQUIREMENTS

INTRODUCTION

One of the key inputs into the process of costing military activities is the estimated manpower needed for operation, maintenance, and support. Personnel requirements are important because they are used not only in the direct computation of pay and allowances and formal training costs, but also indirectly in calculating the costs of several other elements of weapon system cost. Added together, these elements comprise a significant part of the total cost of the system.

Manpower requirements reflect in a great many ways the characteristics of a weapon system and its operating concept. For example, the technical features and reliability of the mission equipment are reflected in the kinds of technical skills and the numbers of people possessing these skills. Anticipated wartime deployment of the system is reflected in number and kinds of support troops as well as the quantity of extra personnel on hand to allow for casualties, etc. Future space systems, with their specialized equipment required to keep man alive in a hostile environment, will generate special requirements regarding size, training, and talents of the space crew. Thus it is important that as an input to the costing process, estimates of manpower requirements take full account of the characteristics of the total system—especially the major equipment and the peak workload implied by the operational concept.

The technical features and operational concepts of all weapon systems—both current and future—are so varied that the methodology of estimating manpower requirements cannot easily be reduced to generalized statistical

formulae and mechanical rules. Particularly for future systems, estimating techniques must of necessity rely to a considerable extent on judgment based on familiarity with the engineering features of the mission equipment and an understanding of how the equipment will most likely be used in an Air Force organizational and operational context.

Manpower requirements for a new system which have been estimated after careful study of information and data about the weapon itself and formulation of appropriate military organizational structures and operational workloads, will provide a solid foundation upon which system costs can be computed. It is important to point out that the organizational structure of squadrons, wings, supporting commands, etc., that must be considered or designed by a person when preparing manpower estimates, forms the skeleton around which many of the elements of weapon systems and total force structure costs are built.

Manpower requirements mean the total number of people (military, civil service, or contractor) for a system defined, if possible, by grade and occupational distribution. These can be measured for costing purposes either in terms of the numbers most probably "assigned" or "authorized," although only the latter will be described in this Appendix, to an operating unit and its direct support units plus allocated numbers of people in the indirect support units. Manpower for the operating units (e.g., detachments, squadrons, groups, wings, divisions and forces) are usually enumerated in detail. Direct support units are those that are assigned to the same using command (e.g., SAC, TAC, ADC) as the combat unit. Manpower for other units indirectly supporting the combat force and usually commanded by the support major commands of the Air Force (e.g., AMC and ATC) are

enumerated in system manpower summary totals or accounted for indirectly through other dollar categories.

METHODOLOGY FOR CURRENT SYSTEMS

Systems with Standard Operations

For weapon and support systems that are in existence or in official Air Force programming publications, the determination of manpower requirements is in most cases a fairly straightforward process. Air Force documents usually exist for these systems which give the manpower authorization already established and computed by appropriate military staffs. The problem is mainly one of locating the most current authorization document for the combat unit and its support units that are appropriate to the organizational and operational concepts of the study.

There are several manpower documents which are designed to provide the Air Force with different amounts of detailed information for management planning and control. For most purposes where manpower information is needed for weapon system costing, the following documents are useful:

(1) Organization Tables (formerly Tables of Organization and Equipment). These documents of three or four pages are published by HqUSAF, and present manpower requirements by skill (i.e., Air Force Specialty Code) and grade (i.e., General, Colonel, Major, etc.) for many types of existing squadrons. Over 500 of these have been published since the OT system was adopted in 1955. These OT's replace an older system which consisted of T/O's (Tables of Organizations) supplemented by T/D's (Tables of Distribution) and T/DA's (Tables of Distribution - Augmentation). Some T/O's are still used along with the new OT's.

(2) Unit Manning Documents. These documents, which are revised fairly

often, present the most up-to-date total authorization of manpower by AFSC and grade for specific units of the Air Force. They are prepared and published with HqUSAF review by the appropriate major command headquarters or their subordinate headquarters. In 1954, the UMD's were initiated to overcome by consolidation the unwieldy nature of the T/O's, T/D's, and T/DA's. Even with the specialized UMD, however, it was realized that a generalized planning document is still desirable, and as a consequence the OT system was adopted. The OT's are computed by averaging the UMD's for similar types of units.

(3) Qualitative Personnel Requirements Information (QPRI). The QPRI is a report prepared by a weapon system contractor during the research and development stage of a new Air Force system. It usually presents both qualitative and quantitative data on operational and maintenance personnel requirements.

(4) Other Documents. There are several official publications that contain useful data for preparing generalized manpower requirement inputs for weapon system costing. Most of these, such as "Organizational Table Summary of Typical Unit Strengths," January 1959, Department of the Air Force, present total military and civilian manpower "authorization" figures for squadrons, wing headquarters, etc., for various kinds of systems, such as strategic bombers, tactical bombers, and fighter-interceptors. Some of these documents, particularly those showing strengths for officially programmed Air Force units assigned to specific bases, are quite useful but not always readily available. "Assigned" strengths can be found in various reports showing the numbers of "people" on hand as of some given time. These reports cover different degrees of detail from Morning Reports of

some specific squadron for a specific day to monthly IBM machine summaries prepared by Statistical Services, HqUSAF.

Systems with Unusual Operations

If the current weapon system being costed assumes an operational concept different from the one for which requirements have already been established by the Air Force, manpower estimates cannot be obtained directly from the previous sources. Adjustments must be made to the manpower authorizations of the basic documents. These adjustments may stem from differences in basing concepts, degree of dispersal, maintenance concepts, personnel utilization rates, geographical locations, etc. They can be computed either by making gross corrections to total strength figures based on generalized statistical estimating techniques, or by making specific corrections to the strength figures of detailed functions within the over-all total organization.

For adjusting manpower requirements by organizational function* for existing systems, Manpower Policy and Criteria, Air Force Manual 26-1, is very useful. However, many unusual operational conditions specified for weapon system costing will be outside the scope of this document. Such cases require research on analogous current systems in order to establish a relationship between some unit measurement of the workload of a function and the number of people required for that function.

Table A-1 presents a typical format used for summarizing requirements for many existing types of SAC aircraft weapon systems operating under essentially normal workload conditions. A set of additional columns is included and can be used to enter adjustments for unusual workloads.

---

*For example, see Air Force Manual 20-3, USAF Function Classification Organization Nomenclature.

Table A-1

ILLUSTRATIVE FORMAT FOR MANPOWER REQUIREMENTS SUMMARY

		Current Requirements							Adjustments							Projected Requirements						
		Military			Civilians				Military			Civilians				Military			Civilians			
Unit	Manpower Source Document	Officers	Airmen	Total	DAF	Contractor	Total	Total	Officers	Airmen	Total	DAF	Contractor	Total	Total	Officers	Airmen	Total	DAF	Contractor	Total	Total
DIRECT REQUIREMENTS																						
Wing headquarters																						
Air refueling squadron																						
Field maintenance squadron																						
Armament & electronics maintenance squadron																						
Organizational maintenance squadron																						
Combat support group headquarters																						
Operations squadron																						
Combat defense squadron																						
Food service squadron																						
Installations squadron																						
Transportation squadron																						
Supply squadron																						
Aircraft support squadron																						
Aviation depot squadron																						
Medical group																						
Total Direct Requirements																						
Add: Augmentation for special or unusual workload not covered by documents																						
Total Direct Requirements (with adjustment)																						
INDIRECT REQUIREMENTS																						
Higher headquarters (if appropriate)																						
Logistics support																						
Total Indirect Requirements																						
GRAND TOTAL REQUIREMENTS																						

Those systems operated by other combat major commands (TAC, ADC, PACAF, etc.) require slightly different formats depending upon the specific organizational structures of combat wings, groups and squadrons authorized by the command. Systems other than aircraft--such as missile and electronic command and control systems--also require somewhat different formats.

Manpower requirements derived directly from UMD's in particular, and O/T's in general, do not necessarily reflect appropriate allocations to specific weapon systems. The UMD's, for example, in many cases represent requirements for systems which either support, or are supported by, other types of systems occupying the same base. A combat squadron of a fighter interceptor system may be assigned as a "tenant" on a SAC base and receive some of its logistics and base support from the "host" SAC combat wing. For many cost studies it is important that these "joint" costs, in terms of number of personnel, be "allocated" to the respective systems.

METHODOLOGY FOR ADVANCED SYSTEMS

Background

Data sources and techniques for estimating manpower requirements for existing systems are not entirely satisfactory for advanced systems. The more advanced the system under study, the less chance there is that procedures mentioned in the preceding section will solve the whole problem and the mo[illegible] the attention that will have to be given to the initial preparation of the basic concept concerning the functions of man in the system, the military organizational structure, and the man-machine relationships that are critical to combat effectiveness.

This section describes in general terms the procedures used at RAND for preparing the basic design of the "personnel subsystem" prior to the official QPRI for the system, and for the estimation of manpower requirements based on this design. These procedures were developed by RAND's Cost Analysis Department primarily for costing purposes and therefore are oriented toward only one facet of a personnel subsystem--i.e., providing a quantitative measurement of personnel resource requirements as an input to system or force structure costing.* The philosophy and techniques presented here reflect both work performed in the past on systems which are now entering the Air Force inventory and on information collected to date on possible future equipment. As more technical information on advancements in the state-of-arts in equipment design and operation is collected, the following procedures will be modified.

Personnel Subsystem

A model of a personnel subsystem is shown in Fig. A-1.

---

*See Personnel Subsystem Management, joint ARDC-ATC Policy in Management of Personnel Subsystem Development for Weapon/Supporting Systems, 1 Feb. 1960.

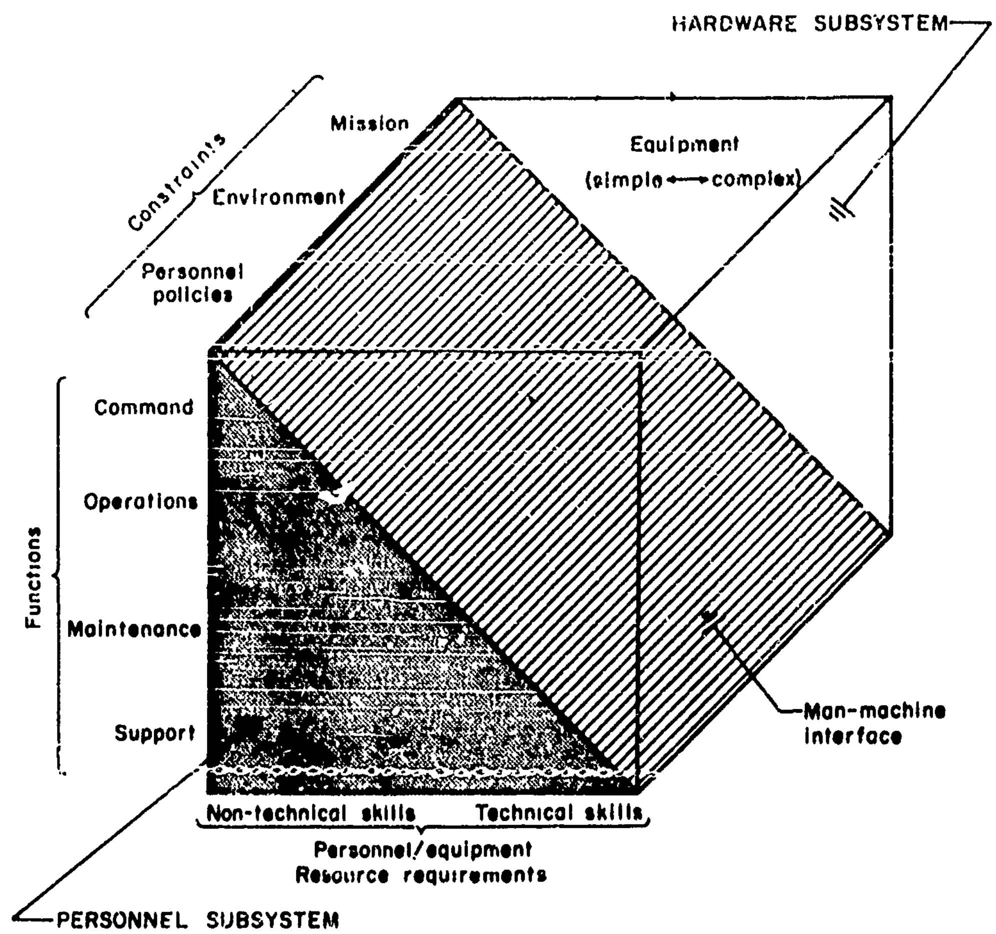


Fig. A-1 — Model of a personnel subsystem

This is intended only as a simplified visual aid to emphasize important factors and to show interrelationships in a total system context. There is no orthogonal significance intended between the various sets of factors even though they are diagrammed on various axes of a "cube."

Conceptually, the "cube" depicts the resource requirements of a total system--both the personnel subsystem and the hardware subsystem in the broad sense. Obviously these requirements are dependent upon certain elements or factors and conditions concerning the objectives of the systems. The "cube" merely portrays these factors in a simplified fashion. The hardware subsystem represented by the upper right portion of the "cube" does not concern us here, except for types of equipment descriptive data, such as reliability information, needed to predict types of skills and quantities of people. The personnel subsystem represented by the lower left portion of the "cube" shows the relationship of the resource requirements to what people do (functions), and the primary "constraints" that are imposed by the nature of the mission, the operating environment, and Air Force institutional personnel policies.

The vertical left plane depicts all functions in which personnel are involved in a system. In the aggregated form shown here, they represent a common set of general functions found in every military system from the point of view of a total system context. The major subtitles of command, operations, maintenance, and support describe general groupings of homogenous activities which can be defined and further subdivided into a variety of tasks, for example, according to standard functional-organizational nomenclature recognized by Air Force personnel planners. These task subdivisions, particularly in the operations category, will depend

heavily upon the type of weapon or support system being considered. For example, space systems would include certain booster launch tasks and satellite data gathering tasks, whereas future aircraft might include aircraft crew tasks and certain ground handling crew tasks.

The third dimensional top plane depicts major constraints or parametric conditions under three categories, (1) mission, (2) environment, and (3) personnel policies. Included under "mission" would be the general workload characteristics of strategic, defense, tactical, and support operations of the particular system under study. These might describe the length of the combat mission flown by aircrews or space crews or the duration of critical monitoring duties performed by launch crewmen during the combat countdown of a missile. If carried to the extreme (which is possible much later in the development process), the detailed output of each task would be described; however, aggregated workload statements, such as the number of boosters fired per month or the number of missiles malfunctioning per month will be all that can be described for advanced planning. "Environment" refers to such things as geographical location (e.g., arctic and tropics); proximity to social and industrial communities and the degree of isolation from civilian or normal military support functions; and the type of immediate physical surroundings of the critical personnel both during peacetime and wartime. Information concerning force size (i.e., total number of weapons considered), degree of dispersal, mobility, and critical alert conditions could be included. "Personnel Policies" would include utilization rate (e.g., eight hour day - forty hour week), ZI and OS rotation period, career development and training, time-in-grade, officer-airman ratios, grade structure ratios by

technical and nontechnical occupational fields, and the extent to which contract services will be used as a substitute for military personnel.

The vertical front plane depicts the personnel-equipment resource requirements of the total system. Perhaps, types of skills would be represented by the personnel subsystem half of the "cube" and the other half by items of equipment corresponding to the skill requirements. It is the interface between these two halves, the trade off between man and machine, that is of great interest to the "human factors" analyst as well as the operations analyst.

General Methodology

The sequence of steps that may be taken to develop the personnel subsystem and the estimates of manpower requirements is illustrated in Fig. A-2. The particular step at which one begins this flow depends on, of course, the type and degree of completeness of contractor and Air Force available documentation that is pertinent to the system under study. If a Development Plan exists, it is necessary to begin only with the "design system organization" or perhaps with "develop task groups."

In many cases, the system idea, which is represented on the chart by a wavy line, is very nebulous, and perhaps was only recently developed from rough analyses of enemy threats and friendly capabilities based on expected advances in technology. It would be necessary to begin with:

1. Develop Mission Concept. This might include such things as an examination of the overall military environment at the time period specified by the system idea, the coordination and/or conflict with other missions for the same period, and specification of the combat capability.

2. Develop Operational Context. General ideas about major new items

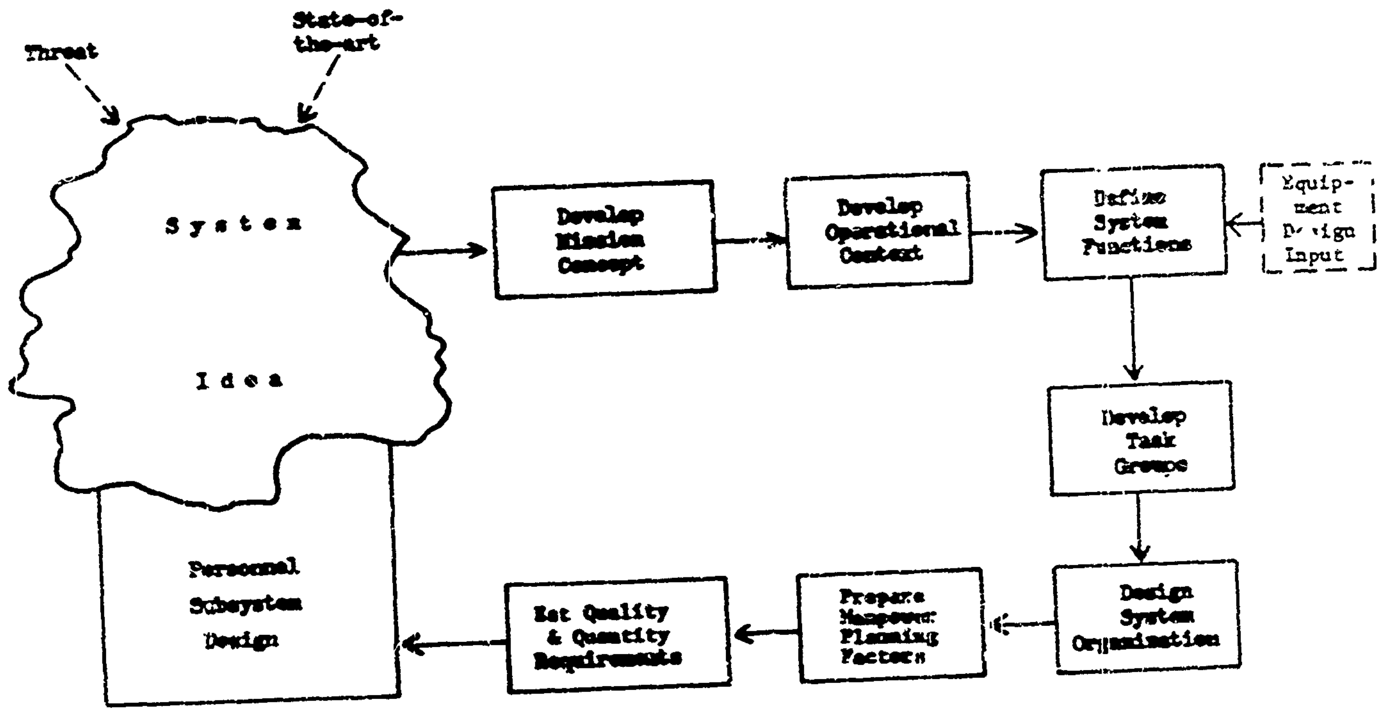


Fig. A-2. SEQUENCE OF STEPS FOR DESIGN OF A PERSONNEL SUBSYSTEM

of combat equipment, ground support equipment, base facilities, maintenance and logistic support, personnel training, transportation, security, and many others, have to be set forth in a coordinated description of the system and how it is expected to operate as an Air Force organization under peacetime and wartime conditions.

It is especially important to have clearly in mind the post-attack environment as it applies to the critical functions that personnel must perform under the physical and mental handicaps imposed by combat conditions. Relative neglect of the post-attack environment may lead to underestimates of manpower requirements.

The number of weapons and their geographical dispersal gives some indication, for example, about the complexity of the hierarchical organizational structure required for over-all command and control of the complete system. The reaction time to respond to enemy tactical warning postulated for the system will indicate the utilization of launch crews--essentially how many people per shift and how many shifts per day are required to maintain continuous efficiency of the mission.

3. Define System Functions. The major functions of the system from factory to launch must be defined. This is essentially a simplified "flow analysis" of which the activities of testing, operating, maintaining, and supporting the mission equipment are broken down into functions. These should be identified by time phases within the life cycle of the system from the time it enters R&D to its final use against an enemy. They should also be identified by general location (e.g., test facilities, operational launch site, control room, depot, remote tracking site, and contractor factory). This can be achieved by study of:

a. Engineering reports describing the proposed major equipment.

b. Engineering reports on analogous current equipment.

c. Demonstrations or inspection of the operation of analogous equipment in military field environments.

4. Design Task Groups. Various segments within the general flow of systems functions need to be explained in detail. Usually, those functions most directly related to the accomplishment of the combat mission are given the most attention--e.g., aircrews for combat aircraft, launch crews for missiles, and radar operators for surveillance equipment. Next, maintenance functions, such as mobile, flight line, organizational and field, will require examination. Base support and housekeeping activities should also be defined. Functions required beyond these more immediate types--AMC depot maintenance and ATC training--can be treated in more generalized fashion. The results of this analysis should appear somewhat like the checklist described in Table A-2.

5. Design System Organization. Certain tasks should be combined and organized into some hierarchical structure that represents a homogeneous grouping of activity. This structure should recognize but not be restricted by Air Force institutional practice with regard to organization of detachments, squadrons, wings, etc. Intra- and inter-unit supervision, both line and staff, should be included according to reasonable standards concerning proper span of control.

These organization design problems can be made easier by reference to the following:

a. Organizational theory from the management planning point of view.

b. General industrial personnel practice.

c. Military personnel practice with regard to utilization, training, efficiency, etc.

6. Prepare Manpower Planning Factors. Each of the functions that has been defined in step five represents a workload and requires some number of military, civil service, or contractor personnel. The determination of the mathematical relationship between numbers of people required and variations of workload for many of the advanced system functions can for the most part only be a judgment. For others there may be existing manpower requirement "standards," such as in AFM 26-1. Manpower "workload-requirement" relationships for advanced systems are being worked on at RAND. The preparation of these relationships should consider such things as (1) man's endurance capabilities, (2) normal ineffective time on the job, (3) average time lost for illness, leaves, and other duties not job-oriented but beyond the control of the worker, etc. Workloads should consider malfunction rates particularly for components of the major equipment which may be estimated from empirical data on analogous existing components.

7. Estimate Quality and Quantity Requirements. The preparation of the personnel subsystem and the planning factors as described in steps one through six should provide the necessary material for a straightforward estimation of quantitative manpower requirements.

MANPOWER ESTIMATING WORKSHEET

Tables A-2 and A-3 show typical check list worksheets for the preparation of manpower estimates for advanced weapon systems. Table A-2 is for space systems. Table A-3 presents modifications of parts of the first list which may be useful for command and control systems. A space system may obviously perform some part of a command and control mission. However, for "C&C" systems in general, the functions of command

and administration and certain intelligence operations require specific definitions as illustrated in Table A-3.

The space system list suggests categories of types of personnel that will most likely be required to perform tasks of testing, operating, maintaining, administering and supporting new systems. The categories are not designed to exhaust all possibilities and it is recognized that for certain advanced systems, some categories will not be appropriate and others should be added.

Although the check list is quantitatively oriented to satisfy the needs for manpower inputs to system costing, the qualitative implications of advanced system characteristics on personnel should not be overlooked. It is equally important to indicate the implications of hardware specifications on such things as skill, experience, and training requirements. The objective is to discover whether the proposed advanced system creates any unusual demands upon Air Force manpower resources that will be difficult, costly, or impossible to satisfy.

In preparing manpower estimates, for the categories shown in the check list, the following concepts should be kept in mind:

1. Total Activity Manpower. The over-all objective is to determine the total additional manpower required by the nation to develop, test, and manufacture, maintain, operate, and support the complete system over a period of years.

2. Consistency of Method. Evaluation of future system proposals involves in many cases the comparison of alternatives. Estimates of manpower requirements for these alternatives must be prepared in some consistent manner in order to avoid introducing biases that may discriminate

against some alternatives relative to others. Some ideas to improve consistency are:

a. Degree of coverage represented by the estimates for systems far in the future is more important than a high degree of accuracy. Manpower for <u>all tasks</u> within the life cycle of the system must be accounted for and described in the final report.

b. Estimates should represent total personnel required for performance of all conventional tasks on a standard Air Force utilization rate, say 8-hour day, 40-hour week, per man basis. Tasks requiring personnel working for longer than 8 hours per day must reflect multiple shifts depending upon weekly duration required to satisfy the mission and the average productive time lost by personnel due to illness, leaves, etc.

c. Estimates of manpower requirements for unusual tasks, such as space tasks, should be constrained only by the physical limitations of the human operator under the unusual environmental conditions of space and not by an artificial limitation of a 40-hour week imposed on earth-side jobs.

Table A-2

Check List

MANPOWER REQUIREMENTS FOR SPACE SYSTEMS
(Illustrative Example)

Categories	Estimates of Manpower Requirements (Military, Civil Service, Contractor)				
	Per Unit			No. Units	Total System
	Per Shift	No. of Shifts	Total Per Unit		

I. Direct Personnel

A. Ground Personnel

1. Administration
   a. Launch Complex
      (1) Command
      (2) Staff
      (3) Administration
      (4) Other
   b. Control Center
      (1) Command
      (2) Administration
      (3) Operations Staff
      (4) Training Staff
      (5) Range Safety
      (6) Other
   c. Guidance Site
      (1) Command
      (2) Staff
      (3) Administration
      (4) Other
   d. Rear Support Base
      (1) Command
      (2) Administration
      (3) Operations Staff
      (4) Maintenance Staff
      (5) Supply Staff
      (6) Other

2. Operations
   a. Launch Complex
      (1) Pad Crews
      (2) Fueling Crews
      (3) Complex Crews
      (4) Planning & Scheduling
      (5) Other

Table A-2 (Cont'd.)

Categories	Estimates of Manpower Requirements (Military, Civil Service, Contractor) Per Unit: Per Shift	Per Unit: No. of Shifts	Per Unit: Total Per Unit	No. Units	Total System
2. Operations (Cont'd.)					
b. Control Center					
(1) Launch Sequence					
(2) Monitoring					
(3) Checkout					
(4) Other					
c. Guidance Site					
(1) Launch & Guidance Activity					
(2) Monitoring					
(3) Checkout					
(4) Other					
d. Space Vehicle Recovery					
(1) Crash Reserve					
(2) Flight Line					
(3) Weather					
(4) Other					
3. Maintenance					
a. Launch Complex					
(1) Component Replacement					
(a) Booster					
(b) Payload					
(2) Calibration					
(3) Other					
b. Control Center					
(1) Component Replacement					
(2) Calibration					
(3) Other					
c. Rear Support Base for Launch Complex & Control Center					
(1) Module Replacement					
(2) Mobile Maint. Teams					
(3) Bench Maintenance					
(4) Minor Assembly					
(5) Modification & Labs.					
(6) Checkout					
(7) General Maintenance					
(8) Job Control					
(9) Instrumentation					
(10) Other					

Table A-2 (Cont'd.)

Categories	Estimates of Manpower Requirements (Military, Civil Service, Contractor)				
	Per Unit			No. Units	Total System
	Per Shift	No. of Shifts	Total Per Unit		
3. Maintenance (Cont'd.)					
d. Assembly & Repair Base					
(1) Assembly of Major Components					
(2) Component Repair					
(3) Shop Maintenance					
e. Depot					
(1) Major Maintenance					
(2) Manufacturing					
(3) Assembly					
(4) Other					
4. Logistic Support					
a. Base Security					
b. Supply					
(1) Shipping, Rcvg.					
(2) Warehousing					
(3) Fuel Mfg. & Storage					
(4) Other					
c. Installations Maintenance					
d. Food Service					
e. Motor Transportation					
f. Medical					
g. Communications					
h. Other					
5. Total Direct Ground Personnel					
B. Space Personnel					
1. Satellite					
2. Space Station					
3. Other Space Vehicles					
4. Space Base (e.g., Lunar)					
5. Total Direct Space Personnel					
C. Total Direct Personnel					

Table A-2 (Cont'd.)

Categories	Estimates of Manpower Requirements (Military, Civil Service, Contractor)				
	Per Unit			No. Units	Total System
	Per Shift	No. of Shifts	Total Per Unit		
II. Indirect Personnel					
A. Logistic Support					
1. Military Support Major Commands (e.g., AMC, ATC)					
2. Contractor Support					
a. Factory "On Site" Assembly					
b Factory "On Site" Repair					
c. "Off-Site" Maint. & Repair					
B. Administrative Support (Allocated portion of superior commands, if directly identifiable)					
C. R&D Support					
1. Military Support (Additional military personnel required at Atlantic & Pacific Test Ranges)					
2. Contractor Test Personnel (Required for test & evaluation at Atlantic & Pacific Test Ranges)					
D. Total Indirect Personnel					
III. Grand Total System Manpower					

Table A-3

Check List of Possible Modifications of Table A-2

MANPOWER REQUIREMENTS FOR COMMAND AND CONTROL SYSTEMS
(Illustrative Example)

Categories

I. Direct Personnel

A. Command and Administration

1. Command
a. At line combat units
(1) Controlling
(a) Operational (forces, weapons, targets)
(b) Financial
(c) Logistics
(2) Assessing
(a) Friendly capabilities
(b) Enemy capabilities
(c) Enemy intentions
(3) Planning
(4) Staffing
(5) Organizing
(6) Coordinating
b. At support units
(1) Controlling
(a) Logistics
(b) Financial
(2) Planning
(3) Staffing
(4) Organizing
(5) Coordinating

2. Administration
a. At line combat units
(1) Peacetime staff activity not covered in No. 1
(2) Others
b. At support units
(1) Peacetime staff activity not covered in No. 1
(2) Others

B. Operations

1. At Intelligence Units
a. Sensing crews
(1) Electro-magnetic missions
(2) Chemical effects
(3) Objects

Table A-3 (Cont'd.)

<u>Categories</u>

(4) Documentary Information
(5) Geographical and seismological phenomena
(6) Atmospheric phenomena
(7) Underwater phenomena

b. <u>Information transfer group</u>
(1) Internal
(2) External

c. <u>Evaluating group</u>
(1) Identification
(2) Measurement
(3) Classification

2. <u>At Higher Headquarters Units</u>

a. <u>Data reception and processing group</u>
b. <u>Data presentation group</u>
c. <u>Data utilization group</u>
d. <u>Secondary evaluation group</u>